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AGRICULTURAL NONPOINT SOURCE POLLUTION OF WATER:

A Literature Survey from an Alberta Perspective

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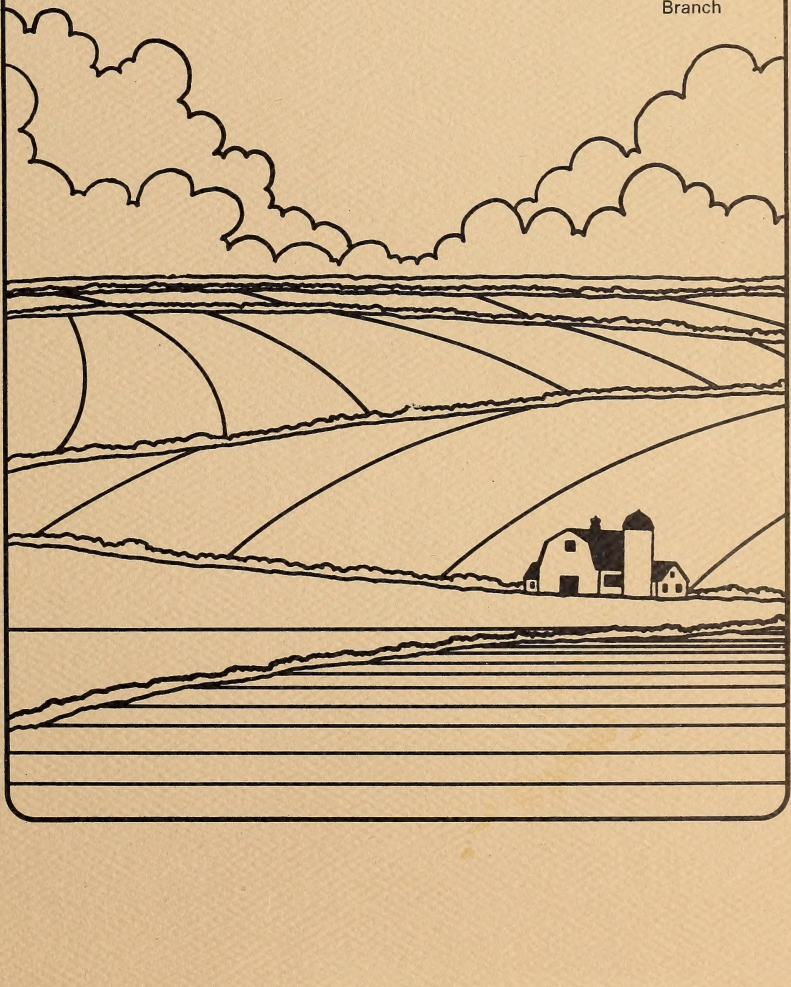

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AGRICULTURAL NONPOINT SOURCE POLLUTION OF WATER:

A Literature Survey from an Alberta Perspective

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PREFACE

Surface water and groundwater can be contaminated by pollutants from nonpoint sources (i.e., broad areas such as fields or forests) and point sources (i.e., individual points such as industrial plant return flows). Over the last two decades, as control of point source pollution has improved, attention has turned to nonpoint source pollution. Agricultural nonpoint source pollutants include sediment, animal wastes, fertilizers, pesticides, nutrients and salts.

Although research on agricultural nonpoint source pollution in Alberta is still in its initial stages, the province is in a good position to take advantage of the information and expertise developed elsewhere in North America. David Neilson, Head, Farm Water Management Section, Conservation and Development Branch, saw the need for this literature survey and initiated the work on it.

The information on water quality and agricultural nonpoint source pollution changes almost daily. This survey focuses on articles published in North American research journals and other sources from the late 1970s to December 1992. The survey is not all-inclusive but it summarizes the understanding of the main water quality issues related to agriculture in Alberta. It is designed for Alberta regional specialists, field staff and others interested in becoming familiar with this topic. While this report provides some initial assessments on what are key water quality issues for Alberta, the rapid changes in this field limit these assessments to the period covered by the survey.

Chapter 1 outlines key results from agricultural nonpoint source pollution research. Chapter 2 describes the Best Management Practices recommended for improving agriculturally affected water quality. Chapter 3 describes water quality models for surface runoff, water table management and groundwater. Chapter 4 outlines the principles involved in planning projects to control agricultural pollution of water. For those interested in an overview, reading sections 1.1 to 1.4 of Chapter 1, the conclusions of Chapters 2 and 3 and all of Chapter 4 is recommended.

Quang-Tuan Nguyen is a second year Mechanical Engineering student in the Cooperative Engineering Program at the University of Alberta. This literature survey was conducted as part of his first work term, September to December, 1992. The assistance of Robert Bateman, Head, Library Services Branch, and his staff is very much appreciated in helping Nguyen with his search for articles. Carolyn King provided significant editorial review for this report.

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EXECUTIVE SUMMARY

This literature survey summarizes work on agricultural nonpoint source pollution in North America, focusing on articles published in North American research journals and other sources from the late 1970s to December 1992. The survey is not all-inclusive but it summarizes the understanding of the main water quality issues related to agriculture in Alberta. It is designed for regional specialists, field staff and others interested in becoming familiar with this topic.

The survey reviews work in four areas. Chapter 1, Research and Monitoring, summarizes studies of agricultural nonpoint source pollution in prairie Canada, eastern Canada and the United States. Chapter 2, Best Management Practices, outlines production practices and control methods for reducing agricultural pollution. Chapter 3, Water Quality Models, describes recent software models used to predict levels of agricultural pollution and improvements in water quality with changes in practices. Chapter 4, Planning Principles for Nonpoint Pollution Control Projects, outlines effective planning principles based on successful pollution control projects. Each chapter includes summaries of individual articles, reports and other information sources, and ends with a summary of conclusions from the literature.

The extent and severity of agricultural nonpoint source pollution of water is not yet well defined for Alberta. At present, it appears that it is neither severe nor widespread. However, recent studies have found herbicide residues in shallow water tables in irrigated areas that in rare instances exceeded drinking water guidelines. Also, nitrate concentrations above the drinking water maximum of 10 mg/L have been found in shallow water tables under fields in irrigated areas where applications of manure were at the maximum recommended rates. On a watershed basis, winter feeding areas for cattle are being investigated as a source of nutrients for algae blooms in Alberta lakes and of drinking water treatment problems in Alberta rivers. None of these studies have yet found serious health hazards to Albertans.

In general, the severity of agricultural nonpoint source pollution is related directly to the intensity of agricultural production. Alberta's agriculture industry is predominately extensive, not intensive. As a result, Alberta researchers are not finding the degree and extent of water quality degradation found in some other parts of North America. Nevertheless, the potential exists for water quality degradation over the long term, particularly if agricultural operations intensify.

Prevention of water pollution from agricultural sources is much more cost-effective than attempting to restore polluted waters to pristine conditions. Recent field studies in the United States have identified Best Management Practices (BMPs) for controlling sediment, pesticide, nutrient, salt and microorganism pollution of water. BMPs include water quality management practices related to management of feedlot and cow/calf operations, fertilizer and pesticide

management, irrigation water management and manure handling.

BMPs must be tailored to local conditions but field evaluation of these practices can be expensive and time-consuming. Therefore, water quality models may be used as a cost-effective alternative to field evaluations, once the models are validated and verified. With climate, crop, soil and topographic information, these computer models can help assess the impact of agricultural activities, identify target areas for BMPs implementation and evaluate BMPs under various scenarios in seconds or minutes.

Several water quality projects in North America have shown that water pollution from agricultural nonpoint sources can be controlled at a reasonable cost with existing technology and approaches. The principles contributing to the success of these projects provide a useful framework for planning the development, implementation and evaluation of future water quality projects.

Education on effective production practices and proper handling of agricultural chemicals is the key to water quality protection. Watersheds with specific water quality problems require targeting of "hot spots" and one-on-one work with key farmers to adopt a mix of Best Management Practices that are practical and feasible for the farmer.

For Alberta's agricultural sector, water quality is an important issue even though the limited available evidence suggests there is no serious agricultural pollution problem yet. While questions about agricultural pollution may be driven by findings elsewhere in North America, Alberta farmers recognize what could be at risk is the health of their families and livestock, and the public's perception that agriculture in Alberta grows food in a clean and healthy environment. Farmers want to know if there really is a water quality problem due to agricultural activities in Alberta.

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1.0 RESEARCH AND MONITORING

1.1 INTRODUCTION

Surface water (lakes, rivers, streams and ponds) and groundwater can be contaminated by pollutants from a number of point and nonpoint sources. Point sources may include improperly designed or defective underground pipelines and tanks, septic systems, oil drilling operations, municipal landfills, and other waste storage and disposal facilities. Nonpoint sources can include urban runoff and lands affected by activities related to agriculture, silviculture, mining and construction.

In recent decades in North America, much progress has been made in point source pollution control. In the past two decades public concern has turned to nonpoint sources, particularly agricultural activities. Agricultural nonpoint pollutant sources include eroded cropland, feedlots, livestock wintering areas, applications of manure, fertilizers and pesticides, and irrigation return flows. These sources can contribute sediments, nutrients, pesticides, salts, trace elements and microorganisms to water resources.

Agricultural pollutants can have many potentially negative effects. For example, runoff and eroded sediment can carry nutrients, pesticides and salts to surface waters. Excess phosphorus (P) in streams and lakes results in algae blooms which can cause low oxygen conditions and fish kills. Pesticides and heavy metals can be toxic to a variety of organisms including livestock and humans. Water polluted with livestock wastes can carry harmful microorganisms. Saline water may affect crop productivity and drinking water quality.

1.2 AGRICULTURAL NONPOINT SOURCE POLLUTION RESEARCH IN ALBERTA

The extent and severity of the problem in Alberta is not yet well defined. Obvious water quality problems are not always the result of industrial or agricultural activities. For example, some Alberta lakes have a history of severe algae blooms in areas of limited agricultural development (Mitchell and Trew 1992).

The likelihood of water pollution is dependent on the intensity of a potentially polluting activity. Although there are agricultural activities in Alberta which can contribute to water pollution, most agricultural operations are extensive, not intensive. Alberta Agriculture (1988) estimated 30% of the province's total land base is used in crop and livestock production. Approximately 9.6 million ha are classified as improved land, including 560,000 ha of irrigated land, and 7.7 million ha of unimproved land. In comparison to agriculture in many other parts of North America, inputs per ha (such as fertilizers, pesticides and water) are relatively low in Alberta (Paterson and Lindwall 1992). Thus, the type, scale and impact of agricultural nonpoint pollution in Alberta may not always follow patterns observed elsewhere in North America.

Although water pollution from agricultural nonpoint sources does not appear to be widespread in Alberta at present, the potential exists for degradation of water quality over the long term, particularly if agricultural operations become more intensive. Therefore, federal and provincial governments have increased water quality monitoring in the province in order to better define the present conditions and establish baseline information for future studies.

Pesticides

Pesticides encompass the chemical and biological agents used to reduce the competitive effects of undesirable plants, insects and other biological pests. Total pesticide use in Alberta in 1986 was estimated at 5,700 tonnes of active ingredients (Davis et al. 1989). Herbicides were the predominant pesticide at 5,251 tonnes.

Initial results from limited water quality reports published in recent years indicate that there is not a serious problem related to pesticides in Alberta's water resources. Hill and Chang (1992) detected low levels of herbicide residues at 11 out of 22 sites sampled under cropland in southern Alberta groundwater in 1991. Six detections occurred on the irrigated half of the field, five on the dryland half. The shallow groundwater contained 2,4-D, diclofop-methyl, triallate and bromoxynil at levels ranging from 0.1 to 2 milligrams per litre (mg/L). These herbicide levels are low compared to the maximum allowable limits of 5 to 230 mg/L given in *Guidelines for Canadian Drinking Water Quality* (Health and Welfare Canada 1989).

In 1991, researchers from the Land Evaluation and Reclamation Branch of Alberta Agriculture monitored herbicide levels in shallow groundwater and subsurface drainage effluent under four sprinkler irrigated fields, and surface runoff and subsurface drainage under a flood irrigated field. Herbicides were detected in the shallow groundwater and subsurface drainage effluent during irrigation events at three of the five sites (Rodvang and Riddell 1992). The detected levels were well below the maximum levels set for drinking water, with the exception of diclofop-methyl*. It was detected at concentrations of 130 mg/L in the shallow groundwater at one site and 137 mg/L in the drainage effluent at a second site. The maximum allowable concentration under the Canadian drinking water quality guidelines is 9 mg/L.

In a study of the Battle River between 1989 and 1990 (Anderson et al. 1991), seven of the

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* Researchers commonly refer to agricultural chemicals by their common chemical names rather than their trade names. Since different products may contain the same chemical, researchers tend to be cautious about identifying a specific product as the source of the chemical. The Glossary in Chapter 6 has a list of trade names and common chemical names for agricultural chemicals.

10 agricultural herbicides or insecticides which have consistent Alberta sales were found in the river. Concentrations of these pollutants were at least three orders of magnitude below the water quality guidelines or objectives providing protection for the most sensitive uses, i.e., protection of freshwater aquatic life and drinking water supplies.

G.G. Shaw (1991) surveyed 142 farm wells in shallow aquifers in Alberta. These wells were identified in Agriculture Canada (1989) as having the highest potential for contamination by herbicide leaching. The criteria for identifying an aquifer as being at "potential risk" were physical characteristics (i.e., shallow water tables overlain by sandy soils), not the type of agricultural activities. Only four samples from southern Alberta had traces of the phenoxy herbicides or triallate and trifluralin tested in this survey. No residues were found in the other 161 samples. The traces of bromoxynil, triallate and trifluralin were well below drinking water guideline limits. As a first survey of aquifers potentially at risk, these results suggest that groundwater contamination is not a widespread problem.

While pesticide levels have been compared primarily to drinking water limits, plants and animals on the fringes of agricultural lands can also be affected by pesticides. In particular, since the Alberta central plains are a key habitat for waterfowl, the effect of pesticides on the food chain in prairie wetlands is a concern. P. Shaw (1992) studied the effects of overspray of field applications of glyphosate on phytoplankton (algae) in prairie ponds. There were no strongly negative effects on phytoplankton, and the herbicide degraded in seven to 11 days.

Irrigation

Much of the Alberta research related to water quality has been concentrated in the irrigation districts of southern Alberta. The total amount of water diverted to Alberta irrigation districts has increased 62%, from 1,661,000,000 m^3 in 1972 to 2,639,000,000 m^3 in 1984 (Barnetson 1985). This increased water use has increased the potential for pesticides, nitrate, salts and trace metals to leach from the soil.

Current research in the Lethbridge area on the impacts of agriculture on water quality includes studies of the effects of irrigation along with such practices as manure application or conservation tillage on concentrations of nitrate, pesticides and salts (e.g. Bolseng 1991b; Chang et al. 1991; Hill and Chang 1992; Rodvang and Riddell 1992).

Results to date suggest that return flow is generally the same quality as diverted water except after storm events (Bolseng 1992a, 1992b, 1992c). The bedrock of southern and central Alberta has naturally high salt concentrations, hence the potential for water salinity problems.

Monitoring of irrigation water along canals and laterals in the Lethbridge Northern Irrigation District, Taber Irrigation District and United Irrigation District in 1989 and 1990 showed no degradation in water quality in irrigation distribution systems in Alberta (Bolseng 1991a). Riddell

(1991) studied drain effluent from the irrigated portion of southern Alberta. He compared water quality data from 1978 to 1984 with 1989-90 data and found no increase in salt or nitrate concentrations. Also, trace element concentrations in 21 samples were below Canadian guidelines for drinking water, aquatic life, livestock, and irrigation water, except for a single manganese value of 0.09 mg/L which exceeded the recommended limits for drinking water (0.05 mg/L) and aquatic life (0.02 mg/L).

Nitrate

Nitrate contamination of water resources may originate from natural sources or from human activities (mainly from human sewage, fertilizers and animal wastes). The degree of agricultural contributions of nitrates to Alberta's waters is not clear due to limited research and interference from natural nitrate sources.

In the Bow River and Taber Irrigation Districts, high nitrate concentrations in isolated pockets in surficial and bedrock deposits have remained relatively stable over the last 10 years (Rodvang 1992). The nitrate originates from natural weathering of bedrock rather than as a contaminant from human activities.

Bolseng (1991a) found nitrate contributions from irrigation return flows in the irrigated districts of southern Alberta to be low. Analysis of irrigation water from canals and laterals in the Lethbridge Northern Irrigation District, Taber Irrigation District and United Irrigation District showed nitrate-nitrogen (NO_3-N) levels ranging from 0.02 to 0.10 mg/L, well below the 10 mg/L limit recommended for drinking water.

Manure Applications

Manure applications to crop land may result in nitrate migration to groundwater, accumulation of salts in the soil and phosphorus transport to surface water. Chang et al. (1991) assessed the impact of long-term cattle feedlot manure applications on the distribution of nitrate in irrigated soil profiles and groundwater. They concluded that the currently recommended rates for feedlot manure application on irrigated and non-irrigated land of 60 Mg $ha^{-1}yr^{-1}$ and 30 Mg $ha^{-1}yr^{-1}$, respectively, are too high. At these rates, nitrates and salts accumulated in the root zone (0-1.5 m) during the 11 consecutive years of manure application, and were subsequently leached beyond the root zone. This excess nitrate is a potential source of contamination for shallow groundwater.

In response to this study, a monitoring program was initiated for the irrigated districts of Alberta (Bolseng 1991b). Soils and shallow groundwater beneath irrigated land where manure was applied were analyzed for nitrate. Groundwater from water table wells at all five sites had nitrate concentrations higher than the 10 mg/L maximum for drinking water. Similar results were obtained in a 1990-91 study (Riddell and Rodvang 1992), in which all five manured sites and one of the three non-manured sites had nitrate concentrations greater than 10 mg/L.

Gammie et al. (1992) found that the timing of snowmelt peak flows from small creeks in agricultural watersheds upstream of Edmonton correlated very well with the timing of maximum discoloration of raw water at Edmonton's water treatment plants. Taste and odour plus the number of livestock in the creeks' watersheds suggest that manure from livestock wintering areas along the creeks may be the source of this water treatment problem.

Uncontrolled Livestock Wastes

Uncontrolled runoff from livestock operations and unrestricted cattle access to watercourses may pollute the receiving waters. In recent years, intensive livestock operations have grown rapidly in number and size throughout Alberta (Goatcher et al. 1991). While other researchers have also looked at the impact of livestock operations on water quality, an integrated team from the Alberta Environmental Centre, Alberta Environment and Alberta Agriculture monitored water quality in watercourses adjacent to four Alberta feedlots between 1985 and 1987 (Goatcher et al., 1991). They concluded that feedlot wastes and runoff contained varying types and levels of microorganisms, nutrients, metals and other contaminants which could adversely impact the quality of receiving surface waters. Although minor to moderate water quality problems existed at the monitoring sites, the adverse impacts of feedlot discharges were generally short-lived, restricted and site-specific.

The impacts of livestock operations have also been considered within broader studies to evaluate the effects of nutrient loading from various land uses on Alberta lakes and their watersheds (Mitchell and Trew 1992). Studies of Lac la Nonne, Pine Lake, Baptiste Lake, Lake Wabamun and the Battle River have linked the intensity of agricultural activities to increasing phosphorus loadings to surface water bodies. The results from the Lac la Nonne study suggested that the amount of phosphorus in inflow streams increases as the number of cattle in the watershed increases (Mitchell and Trew 1992).

The Pine Lake project, initiated in 1990, is Alberta's first attempt to improve a lake's water quality by controlling the nutrient loadings from agricultural and resort areas around the lake shore (Sosiak and Trew 1992). Two water quality models, AGNPS and SWRRB-WQ, are being evaluated for their usefulness to target critical areas and assess management practices. Preliminary results from the Pine Lake study indicate that livestock operations in the Pine Lake watershed contribute to the phosphorus loading of the lake (Sosiak and Trew, pers. comm., 1993).

Phosphorus

Regional lake studies show that agricultural development in Alberta does increase the phosphorus loads to lakes (Mitchell and Trew 1992). However, since many of Alberta's lakes are naturally eutrophic (naturally prone to algae blooms), it is difficult to establish how much agricultural operations contribute to water quality problems. Studies like the Pine Lake project are focusing attention on the role of livestock and manure management. While the public health aspects of manure and livestock management are beginning to receive research, the impacts on algae and water plants and the consequences for recreation and fisheries will continue to be a key issue.

In summary, Alberta studies to date have not found widespread water pollution from agricultural nonpoint sources. However, further research is required to better define the current extent and severity of the problem, and to assess the long-term potential and possible impacts of water pollution from agricultural activities.

1.3 AGRICULTURAL NONPOINT SOURCE POLLUTION RESEARCH IN OTHER PROVINCES

In most other Canadian provinces, the role of agriculture in water quality degradation is generally unclear when compared to other pollution sources. Few published studies clearly identify agriculture as the main cause of poor water quality.

In a small Saskatchewan agricultural watershed, groundwater, surface water and spring runoff were analyzed for commonly used herbicides (dicamba, bromoxynil, 2,4-D, triallate and diclofop) and insecticides (carbofuran, carbaryl, chlorpyrifos, dimethoate and deltamethrin) between 1985 and 1987 (Waite et al. 1992). All five herbicides were detected with varying frequencies and concentrations in groundwater samples. Diclofop was the most frequently occurring herbicide in 35% (37 out of 105) of the samples with a maximum concentration of 4.88 mg/L. The second most frequently occurring pesticide was 2,4-D, found in 10% of the samples with a maximum concentration of 2.07 mg/L. Surface water had lower herbicide concentrations than groundwater. Only four herbicides were detected in the surface water samples: 2,4-D (22 samples), triallate (23 samples), dicamba (15 samples) and diclofop (13 samples). The highest detected concentration was 0.51 mg/L of 2,4-D, followed by 0.47 mg/L of diclofop. Only one site had detectable levels of an insecticide, carbofuran, at 1 mg/L at spring runoff.

Krawchuk and Webster (1987) monitored subsurface (tile) drain outflows draining potholes in a quarter section irrigated by a centre pivot system near Portage la Prairie, Manitoba. The system operated with water from the Assiniboine River, on sandy soils with a high water table and low organic matter (Almassippi Sands). The field was under potato production. In an initial random sampling in 1981, no pesticide residues were detected in the tile outflow at the 0.02 micrograms per litre (μg/L, where 1 μg = 0.001 mg) level. An extensive sampling of the tile outflow in 1982 detected the fungicide chlorothalonil on eight occasions at levels from 0.06 to 3.66 μg/L. One of two shallow water table wells in the field contained chlorothalonil at levels from 10.1 to 272.2 μg/L in 1981, and 0.4 to 0.9 μg/L in 1982. Carbofuran was detected in the shallow water table well at levels of 1.15 to 158.4 μg/L in 1982 and less than 0.5 to 1 μg/L in 1983. Maximum allowable concentrations of carbofuran under drinking water guidelines are 0.09 mg/L (i.e. 90 μg/L) (Health and Welfare Canada 1989). The herbicide 2,4-D also was detected in the shallow water table well at levels of 0.8 to 2.5 μg/L in 1983. Drinking water guidelines for 2,4-D are 100 μg/L. While carbofuran was above drinking water guidelines in the water table just below the crop's root zone, the insecticide was not detected in the tile outflow draining the shallow water table. Dilution effects from the random grid of subsurface drains or tie-up of the pesticides on the polyvinyl chloride (PVC) plastic of the subsurface drain tubing could explain why pesticide detections were limited in the tile outflow.

The Assiniboine Delta Aquifer in Manitoba, a water source for 6000 ha of irrigated cropland, livestock operations and industries, was analyzed for commonly used pesticides (Buth 1992). These pesticides include: atrazine, bromoxynil, carbofuran, chlorothalonil, dicamba, diclofop-methyl, fenoxaprop-ethyl, fonofos, MCPA, methoxychlor, metribuzin, picloram, phorate, sethoxydim, thifensulfuron and 2,4-D. Water samples from 26 irrigation wells had no detectable pesticides, except for chlorothalonil in one well water sample. This could have been due to contamination of the well by an improperly functioning chemigation injection system at the centre pivot. Nitrate was present in groundwater samples from the irrigation wells. In only one water sample did the nitrate level exceed drinking water quality guidelines.

The Great Lakes study, conducted from 1974 to 1977, showed that agriculture contributed significantly to sediment and phosphorus pollution (Coote and MacDonald 1978). Row crops on fine textured soils were a major source of this pollution, and livestock were a minor source. Eutrophication was found to be a primary problem for the Great Lakes.

A survey of 1300 Ontario farm wells in the fall and winter of 1991-92 found that a significant number of wells had contamination by bacteria (31%) or nitrates (13%), but pesticide contamination was negligible (Rudolph et al. 1992). Petroleum contamination was nonexistent. The one well with pesticide contamination above drinking water limits had experienced a spill of the herbicide near the well. Older wells (> 60 years) and shallow dug or bored wells were more likely to be contaminated. Proper manure and septic field management and avoiding pesticide spills near wells were concluded to be essential to avoiding well contamination. Proper sealing of wells from surface runoff and proper abandonment of old unused wells also was highlighted.

In New Brunswick, Milburn et al. (1990) monitored tile drained commercial potato fields. They found two of three areas of the agricultural region had nitrate concentrations in excess of 10 mg/L in wells. The sources of nitrate were nonpoint fertilizer-N and/or soil-N.

1.4 AGRICULTURAL NONPOINT SOURCE POLLUTION RESEARCH IN THE UNITED STATES

Concern over this issue in the United States has sparked investigations of the processes of nonpoint pollution and methods to control it, and development of models to assess the water quality situation before and after appropriate practices have been implemented.

In the 1984 report entitled *America's Clean Water: The States' Evaluation of Progress 1972-1982*, nonpoint source pollution by agricultural activities was cited as "a 'widespread problem' by two-thirds of the states" (Myers et al. 1985). Agricultural practices were identified as impacting surface waters in almost all areas of the United States (except for Alaska and the Virgin Islands). In 36 states, 50% or more of the state's waters were affected by nonpoint source pollution from agriculture/irrigation practices (Myers et al. 1985).

The Rural Clean Water Program (RCWP) is a federal water quality program involving 21 agriculturally affected watersheds across the United States (Gale et al. 1992). Identified impaired water resources include estuaries, streams, lakes, bays, groundwater, rivers and impoundments. The contaminants in each watershed include one or more of the following: pesticides, phosphorus, nitrate and microorganisms. Contaminant sources include swine waste, cropland nutrients, cropland erosion and dairy waste.

In 1990, the U.S. Environmental Protection Agency (EPA) estimated that about 9,850 (10.4%) of the community wells and 446,000 (4.2%) of the rural domestic wells contained at least one pesticide. However, less than 85,000 (0.8%) of the wells surveyed had pesticide levels above drinking water standards (Heacox 1990). According to Lyster (1990), in tests of 150 Corn Belt streams between 1987 and 1989 by the U.S. Geological Survey, 55% of the samples contained atrazine and 34% contained alachlor at levels above recommended drinking water standards.

The EPA also estimated in 1990 that more than half of the wells in the United States contained nitrates, with about 1.2% of the community wells and 2.4% of the rural wells having levels above the 10 mg/L maximum established to protect human health (Heacox 1990). Groundwater contamination from NO_3-N appears to be concentrated in the Central Great Plains, the Palouse and Columbia Basin in Washington, portions of Montana, southwest Arizona, the irrigated fruit, vegetable and cotton growing areas of California, portions of the Corn Belt, southeast Pennsylvania, and parts of Maryland and Delaware (Hurlburt 1988).

Irrigation-related salinity is the major water quality problem in the semiarid western states (El-Ashry et al. 1985). The Colorado River Basin, including the Imperial and Coachella Valleys of southern California that receive Colorado River water, has greater salinity problems than any other river basin in the West. The Rio Grande Basin of New Mexico and Texas, the Central Valley of California, the Yakima River Basin in Washington, the Snake River Basin in Idaho, and the Arkansas

River in Colorado, Kansas and Oklahoma are areas of seriously affected waters. Seepage and return flows from irrigated land cause these rivers to become increasingly saline along their flowpath.

Excessive irrigation on soils naturally rich in trace metals can leach these metals into receiving waters. For example, irrigation of California soils naturally rich in selenium has resulted in leaching of selenium into receiving waters via tile drains (Horne 1988). The Kesterson Reservoir complex, built to store the tile drain effluent, was discovered to contain high selenium levels which caused serious impacts on the nesting success of waterbirds using the reservoir, including embryo defects.

The Great Plains Agricultural Council Water Quality Task Force (1992) found that, "Normal use of agricultural chemicals does not appear to be causing widespread ground water contamination." The task force concluded that intensive agriculture in areas with shallow groundwater and/or sandy soils, septic tanks outflows and activities near farm wells caused most of the major pollution problems. It also found that feedlots and other confined livestock operations, unrestricted access of livestock to surface water, and irrigated areas were the most important sources of agricultural nonpoint pollution in the Great Plains. Unlike other areas of the United States, pesticide pollution of surface runoff (adsorbed to eroded soil particles) in the Great Plains was judged to be low because water erosion is 50% less than the rates for other areas.

1.5 NONPOINT SOURCE POLLUTION RESEARCH LITERATURE SUMMARY

1.5.1 Research in Prairie Canada

Title:	Sediment and runoff water characteristics as influenced by cropping and tillage practices
Authors:	Beke, G.J., C.W. Lindwall, T. Entz, and T.C. Channappa
Published:	1989
Source:	Canadian Journal of Soil Science. 69: 639-647
Study site:	Near Lethbridge, Alberta, Canada
Study period:	Summer 1986
Description:	Runoff water samples, simulated by sprinkler irrigation, were collected from four plots. Plot treatments consisted of: bare fallow with minor surface roughness, continuous alfalfa/stream bank wheat grass, barley sown with the slope, and barley sown on the contour. No fertilizer was applied to any of the treatments during the study. The water samples were analyzed for sediment load, NO_3-N, total nitrogen and phosphate-phosphorus (PO_4-P).

Findings: In southern Alberta's semi-arid climate, rainfall on wet soil or excessive irrigation can cause erosion of soil particles and loss of soluble chemicals by surface runoff. The nutrient composition of the sediment particles is affected by soil conservation practices and is seldom identical to that of the original soil.

Concentrations of NO_3-N, total nitrogen and PO_4-P in runoff from the fallow plots, forage plots and barley plots were not significantly different. Runoff water from all four treatments was enriched in NO_3-N, total N and PO_4-P. While the concentrations were not significantly different, the forage treatment had the largest nutrient enrichment in the runoff water, followed by barley planted on a slope, then barley planted on the contour.

Eroded sediment from all four treatments was generally enriched in organic matter, NH_4-N, total N and PO_4-P, but not in NO_3-N or total P.

Title: Water quality in irrigation distribution systems

Author: Bolseng, T.

Published: 1991a

Source: Pages 28-34 *in* Irrigation and Resource Management Division Applied Research Report 1989-90, 1990-91. Alberta Agriculture, Edmonton

Study site: Lethbridge Northern Irrigation District (LNID), Taber Irrigation District (TID) and United Irrigation District (UID), southern Alberta, Canada

Study period: June 1989 to July 1990

Description: Samples from 18 hydrometric stations located along canals/laterals were analyzed for pH, electrical conductivity (EC), sodium absorption ratio (SAR), cations, anions, trace metals and nutrients (NO_3-N, P).

Findings: The mean EC at all LNID stations remained constant at about 0.30 dS/m, indicating no salt loading. The mean EC for all TID stations in 1989 and 1990 was constant. Mean EC levels for the UID lateral were slightly higher at the tail stations as compared to the head stations in both 1989 and 1990. Most trace metal concentrations were below the detection limit and well within the recommended maximum limits for drinking water. Nitrate levels in all water samples were low, ranging from <0.1 to 0.2 mg/L, and well below the 10 mg/L maximum for drinking water. Similar results were found in 1990-1991 (Bolseng, 1992a).

Title: Migration of nitrates to groundwater under manured fields

Authors: Bolseng, T.

Published: 1991b

Source: Pages 23-27 *in* Irrigation and Resource Management Division Applied Research Report, 1989-90, 1990-91. Alberta Agriculture, Edmonton

Study site: Irrigation districts of southern Alberta, Canada

Study period: 1990

Description: Five sites, representing a variety of soil types, in four irrigation districts across southern Alberta were monitored for nitrate concentration in groundwater under manured and control treatments. Four water table wells, 3 m deep, were installed at each site.

Findings: Nitrate concentrations in shallow groundwater were higher under irrigated, manured conditions than under the control treatments at four out of five sites. The drinking water guideline of 10 mg/L for nitrates was exceeded for all manured sites and two of the three control sites.

Title: Water quality in irrigation distribution systems

Author: Bolseng, T.

Published: 1992b

Source: Pages 51-56 *in* Irrigation and Resource Management Division Applied Research Report 1991-1992. Alberta Agriculture, Edmonton

Study site: Lethbridge Northern Irrigation District (LNID) and Taber Irrigation District (TID), southern Alberta, Canada

Study period: Irrigation season, 1990 and 1991

Description: Samples from 14 locations paired along the upper and lower reaches of laterals were analyzed for pH, electrical conductivity (EC), sodium absorption ratio (SAR), cations, anions, trace metals and nutrients (NO_3-N).

Findings: The mean EC and SAR values along upper and lower reaches of laterals remained constant. Minor fluctuations from year to year were found within a lateral. Differences from one lateral to another could be attributed to biological activities in upstream reservoirs. NO_3-N levels were low (1 to 3 mg/L) and well below the 10 mg/L maximum for drinking water. Most trace elements were below detection limits and trace elements detected were below human, livestock and irrigation maximum limits. Results match those of found in 1989-1991 (Bolseng 1991a).

Title: Impact of subsurface tube drainage effluent on salt and nitrate levels in the Monarch drain

Authors: Bolseng, T.

Published: 1992c

Source: Pages 57-61 *in* Irrigation and Resource Management Division Applied Research Report 1991-1992. Alberta Agriculture, Edmonton

Study site: Lethbridge Northern Irrigation District, Alberta, Canada

Study period: May to November, 1990

Description: Water quality of the Monarch spill drain was monitored. This drain collects and returns groundwater seepage, surface runoff, tile drainage effluent and irrigation spill water to the Oldman River.

Findings: Salt flux (in kilograms per second) of the cumulative outlet ranged from 3.1 to 45.8 kg/s and was 12.3 to 54.1% of the return flow salt flux. Cumulative subsurface drainage outlet NO_3-N levels ranged from 0.0 to 203 mg/L with a median of 2.7 mg/L and a mean of 20.6 mg/L. The deep interceptor drain NO_3-N levels varied from 9.4 to 14.6 mg/L with a mean of 12.0 mg/L and a median of 11.6 mg/L. NO_3-N levels in flowing surface waters at the tail-end of the Monarch drain ranged from 0.0 to 1.3 mg/L, well below the 10 mg/L maximum for nitrates in drinking water.

Title: Waste management: soil chemistry after eleven annual applications of cattle feedlot manure

Authors: Chang, C., T.G. Sommerfeldt, and T. Entz

Published: 1991

Source: Journal of Environmental Quality. 20: 475-480

Study site: Lethbridge Research Station, Agriculture Canada, Lethbridge, Alberta, Canada

Study period: 1973 to 1983

Description: Manure, incorporated by cultivating, roto-tilling or plowing, was applied annually from 1973 to 1983 at 30, 60 and 90 Mg/ha, respectively, on irrigated and non-irrigated clay loam soils.

Findings: The results from the tillage treatments were not significantly different. Constituents were leached deeper on the irrigated than non-irrigated plots. The total nitrate at a soil depth of 1.5 m was near 1 Mg/ha even when manure was applied at recommended rates. This nitrate level is high enough to cause soil and groundwater pollution. Available P accumulated mostly in the surface soil and might be sufficient to interfere with the nutrient balance for some crops. Long-term annual applications of manure at maximum recommended rates (30 Mg/ha for non-irrigated soils and 60 Mg/ha for irrigated soils) is not recommended.

Title: Upstream watershed evaluation

Authors: Gammie, L., D. Rector, and G. Walker

Published: 1992

Source: Paper presented at Western Canada Water and Wastewater Association Conference, Calgary, Alberta, October 14-16, 1992

Study sites: Small creeks in agricultural watersheds between Drayton Valley and the City of Edmonton

Study period: 1989 to present

Description: The timing of peak flows from the creeks were compared to the timing of peaks in the colour of raw water entering the City of Edmonton's treatment plants.

Findings: Excellent correlation was found between the timing of the peak flows of these creeks from spring and summer runoff and the raw water colour at the City of Edmonton water treatment plants. The same correlation did not exist upstream in forested watersheds. Odour data from the creeks appeared to link runoff problems with livestock wastes. Work is under way to identify the organics in water and compare them with the organics of manure and leaf litter.

Title: Impact of cattle feedlot wastes on surface water quality in Alberta: microbiological and chemical surface water quality

Authors: Goatcher, L.J., L.R. Goodwin, A.K. Sharma, M.R. Bennett, B.S. West, F.P. Dieken, and A.A. Qureshi

Published: 1991

Source: Alberta Environmental Centre Report no. AECV91-R2. Alberta Environmental Centre, Vegreville. 181 p.

Study sites: Palmer Ranch, Waterton; Prime Feeder Ltd., Fort Macleod; Wes Yanke Ranch, Medicine Hat; and Adams Ranch Ltd., Czar, Alberta, Canada

Study period: 1983 to 1985

Description: Three cattle feedlots in southern Alberta and one in east-central Alberta were studied to determine the impact of feedlot wastes and associated runoff on the water quality of receiving water bodies. Sampling stations were located upstream of each feedlot, at the feedlot runoff point, downstream of the feedlots in receiving water bodies, and further downstream of the feedlot.

Findings: The impact of the feedlots on surface water quality varied from site to site. Microbial levels at all sampling stations were lowest during spring runoff and highest during storm events. For example, densities of total coliform and faecal coliform at the Palmer Ranch during storm events were approximately two to nine times higher than the maximum recommended levels (1000 and 2000 per

100 mL, respectively) for recreational waters at all sampling stations (above, at and below the feedlot). During spring runoff, total coliform and faecal coliform were 10 to 200 times or more below the maximum levels.

Total coliform, faecal coliform and faecal streptococci may not be reliable indicators of feedlot impact on surface water quality of receiving water bodies. At the Prime Feeder Ltd. feedlot, densities of total coliform and faecal coliform during storm events were similar at all sampling stations (above, at and downstream of the feedlot).

Title: Scientists check for herbicides in southern Alberta groundwater

Authors: Hill, B.D., and C. Chang

Published: 1992

Source: Agriculture Canada Weekly Letter No. 304

Study site: Agriculture Canada Research Station, Lethbridge, Alberta, Canada

Study period: 1991 to present

Description: A partially irrigated 1 ha field was surveyed for herbicide residues. The water table was at 0.5 to 3 m depth on the irrigated half of the field and at 3 to 5 m on the dryland half. Groundwater samples at 22 sites were analyzed for five herbicides (2,4-D, MCPA, diclofop-methyl, triallate and bromoxynil) known to have been applied to the field over the previous five years.

Findings: While no herbicide residues were detected in samples taken in May 1991, residues were found at 11 of the 22 sites in the July samples. The shallow water tables contained 2,4-D, diclofop-methyl, triallate and bromoxynil at levels ranging from 0.1 to 2 mg/L. These levels are well below the maximum allowable concentrations for drinking water.

Sampling protocols are being investigated. Samples from wells constructed with PVC pipe consistently had lower herbicide residues than samples from stainless steel wells. Results for 1992 were consistent with 1991 results, with residues again ranging from 0.1 to 5 mg/L.

Title: Agricultural runoff and lake water quality

Author: Mitchell, P., and D. Trew

Published: 1992

Source: Pages 73-79 *in* Proceedings from Agricultural Impacts on Surface and Groundwater Quality, September 16 and 17, 1992, Lethbridge, Alberta. Land Evaluation and Reclamation Branch, Alberta Agriculture, Lethbridge

Study sites: Various Alberta lakes and their watersheds, Canada

Study period: 1978 to present

Description: Summarizes the findings on nutrient loadings from various watershed and lake studies through central and northern Alberta. Studies monitored watersheds for land activities and nutrient loadings to streams. Lake impacts and processing of nutrients in lakes were also monitored.

Findings: While the total phosphorous levels from streams draining forested lands were quite consistent, the phosphorous concentrations from agricultural lands were highly variable. The Lac La Nonne study suggested that phosphorus increased in the inflow streams as the number of cattle in the watershed increased.

Clearing a watershed also had a marked effect. On Baptiste Lake, the phosphorus load was estimated to increase by 88% as a result of clearing 21% of the watershed. Phosphorus export coefficients calculated from Alberta studies had values for cleared and agricultural land two to five times higher than for forested or bush land. While many Alberta lakes are naturally productive or eutrophic, it is not known how much more eutrophic they have become as a result of watershed clearing.

Title: Loss of fall-applied 2,4-D in spring runoff from a small agricultural watershed

Authors: Nicholaichuk, W., and R. Grover

Published: 1983

Source: Journal of Environmental Quality. 12(3): 412-414

Study site: Swift Current, semi-arid southwestern Saskatchewan, Canada

Study period: 1975 to 1981

Description: Dimethylamine salt of 2,4-D was applied at a rate of 0.42 kg/ha (active ingredient) in the late fall in the stubble of a harvested wheat crop. Surface runoff from snowmelt was collected.

Findings: The loss of 2,4-D was greater from the treated stubble compared with the control (fallow). The average loss from the control was 1.3 g/ha, or 0.3% of the amount applied. The six-year average loss was 4.1% of the amount applied. Correlation analysis showed the amount of loss to be a function of runoff. The average flow-weighted mean concentration of 31 μg/L was well below the U.S. EPA maximum permissible level of 100 μg/L and slightly above the U.S. National Academy of Sciences and National Academy of Engineering objective of 20 μg/L for drinking-water standards.

Title: Subsurface drain effluent monitoring

Author: Riddell, K.M.

Published: 1991

Source: Pages 13-17 *in* Irrigation and Resource Management Division Applied Research Report, 1989-90, 1990-91. Alberta Agriculture, Edmonton

Study site: Irrigated areas of southern Alberta, Canada

Study period: May to November, 1990

Description: Water quality samples and flow measurements were taken on a monthly basis at approximately 43 subsurface drain outlets in the irrigated areas of southern Alberta. The samples were analyzed for cations, anions, nitrates and EC. Samples for trace metal analyses were collected during May, August and November.

Findings: Comparison of historic levels (1977-1984) to recent levels (1989-1990) for salinity, flow and nitrate levels in drain effluent revealed very similar patterns. There was a slight decrease in the occurrence of values greater than 20 mg/L in the 1989-90 data. Twenty-five and thirty percent of all drain outlet samples in the recent and historic data sets, respectively, exceeded the recommended limit of 10 mg/L for nitrate in drinking water.

The median salinity level in the 1989-90 period (6.3 dS/m) was slightly higher than the historic level (4.4 dS/m). Flow and salinity levels from an individual subsurface drainage outlet revealed cyclical patterns with no long-term tendency towards higher or lower salinity or flow levels.

Trace element analyses on 21 drain effluent samples taken in May showed very low concentrations. All concentrations are below Canadian guidelines for drinking water, aquatic life, livestock and irrigation water, except a single manganese value of 0.09 mg/L which exceed recommended limits for drinking water (0.05 mg/L) and aquatic life (0.02 mg/L).

Title: Groundwater quality in the Bow River and Taber Irrigation Districts

Author: Rodvang, J.

Published: 1992

Source: Pages 45-49 *in* Irrigation and Resource Management Division Applied Research Report, 1989-90, 1990-91. Alberta Agriculture, Edmonton

Study site: Bow River Irrigation District (BRID) and Taber Irrigation District (TID), Alberta, Canada

Study period: 1990

Description: Seventy-seven piezometers and water table wells in the BRID and TID groundwater return flow systems were sampled for major ions and trace element concentrations.

Findings: No continuous or significant trends were observed between the 1979-80 and the 1990 groundwater data. High concentrations of salts were detected as a result of natural weathering and dissolution processes. High nitrate concentrations in isolated pockets in surficial and bedrock deposits originate as a natural weathering product rather than as a contaminant. Low levels of arsenic, selenium and lead were detected in many samples, and drinking water guidelines for selenium were exceeded in a small proportion of samples. These metals probably resulted from weathering of minerals in till deposits.

Title: Monitoring of phenoxy-neutral herbicides in subsurface drain effluent in southern Alberta

Authors: Rodvang J., and K.M. Riddell

Published: 1992

Source: Pages 39-45 *in* Irrigation and Resource Management Division Applied Research Report, 1991-92. Alberta Agriculture, Edmonton

Study site: Irrigated districts of southern Alberta, Canada

Study period: Summer 1991

Description: Subsurface drainage effluent and surface runoff were monitored for herbicides at five irrigated sites.

Findings: Herbicide concentrations were comparable between drain effluent, water table wells and surface runoff, although surface runoff tended to exhibit slightly higher herbicide levels.

Minor amounts of all five herbicides which were applied during the monitoring year were detected in surface water and shallow groundwater, although many samples did not contain detectable herbicides. Applied and detected herbicides included diclofop-methyl, bromoxynil, dicamba, MCPA and triallate. All samples exhibited herbicide levels which were well below drinking water guidelines, with the exception of diclofop-methyl, which exceeded guidelines by a factor of about 15 at two sites.

Herbicides not applied during the study year were also detected at low levels at three sites. These included dicamba, mecoprop, MCPA and 2,4-D. All these chemicals are highly soluble in water which may account for their mobility.

Title: Pesticides residues in surface and groundwater

Author: Shaw, G.G.

Published: 1991

Source: Unpublished presentation to Alberta's Municipal Agricultural Fieldmen (April 1991)

Study sites: 142 farm wells located in landscape polygons with coarse textured soils (areas with soil most susceptible to leaching to shallow groundwater) (Agriculture Canada 1989). Some were in Irrigation Districts 8, 11, 12 and 13.

Study period: 1988 to 1990

Description: From farm wells, 36 samples were tested for 2,4-D, 2,4-DB and diclofop-methyl, 13 samples for bromoxynil, and 116 samples for triallate and trifluralin.

Findings: Of the 165 samples taken and tested for phenoxy herbicides or triallate and trifluralin, only four had trace levels of bromoxynil, triallate and trifluralin. All were well below drinking water maximum limits.

Title: Effects of glyphosate (Roundup formulation) on phytoplankton in prairie ponds

Author: Shaw, P.

Published: 1992

Source: Research Report for the North American Waterfowl Management Plan

Study site: Three small, shallow ponds in the Buffalo Lake Moraine, 15 km east of Bashaw in central Alberta, Canada

Study period: Summer 1990

Description: Each pond had two triangular enclosures constructed for 5 m along the shore and 7.5 m into the pond for a total surface area of 18.75 m^2. Polyethylene walls were used to isolate the two enclosures from the rest of the pond.

One of the two enclosures on each pond was sprayed with Roundup at 2.5 L/ha (0.890 kg/ha glyphosate), the recommended field application rate. Background samples for glyphosate were collected in the water and sediments. Chlorophyll "a" levels (an indicator of algae populations in the water) were measured. Samples of the water and sediments were taken one hour after the application of Roundup and daily for 15 days.

Findings: The study showed no strongly negative impacts on phytoplankton from glyphosate contamination. Pond 2 showed some evidence of chlorophyll "a" depression from Roundup application but recovery was rapid and nearly equal to the control by Day 15. Degradation of glyphosate was rapid and declined to detectable limits by Day 10. However, some glyphosate residues were found long past typical residence times. This suggested that by-products from the biota in the pond could produce compounds that could result in "false positives" in analysis for compounds like glyphosate.

Title: Persistence and movement of picloram in a northern Saskatchewan watershed

Authors: Smith, A.E., D.T. Waite, R. Grover, L.J. Milward, H. Sommerstad, and L. Kerr

Published: 1988

Source: Journal of Environmental Quality. 17(2): 262-268

Study period: 1982 to 1985

Study site: Primrose Lake Air Weapons Range, 10 km north of Regina, Saskatchewan, Canada

Description: In the summer of 1982, 477 ha of a weapons range in northern Saskatchewan were treated with a granular formulation of picloram at a rate of 3.38 kg/ha. Water samples were collected within and outside the treatment area for the next three years.

Findings: There was a gradual dissipation of picloram from the treated soil at three sampling locations following the picloram treatment. After 26 months, between 138 and 396 g/ha were recoverable from the top 120 cm of the soil. Picloram in the treatment area underwent extensive leaching with time so that after 14 months, residues were detected at the 60 to 90 cm soil depths, and after 22 months, picloram was detected at 90 to 120 cm.

Picloram was detected in groundwater at 120 cm at locations outside of the treatment area, indicating a mass movement of picloram through the permeable, sandy soil. After 14 and 26 months, traces of picloram were detected in the water of Primrose Lake, 1 km from the treatment area.

1.5.2 Research in Eastern Canada

Title: Agriculture and water quality in the Canadian Great Lakes basin

Authors: Coote, D.R., and E.M. MacDonald

Published: 1978

Source: Canadian Society of Agricultural Engineers Paper no. 78-212

Study sites: Eleven watersheds in the Great Lakes area of Ontario, Canada. The watersheds ranged from 20 to 79 km^2 in area, of which 22% to 89% was cultivated, and 0% to 99% tile drained.

Study period: 1974 to 1977

Description: The watersheds were monitored for two years. Loadings of sediments, phosphorus, nitrate, pesticides and microorganisms from each watershed were estimated.

Findings: The primary pollution problems in the Great Lakes appeared to be eutrophication and the presence of certain toxic materials. Inputs of total phosphorus ranged from 0.2 kg ha^{-1}yr^{-1} to 1.5 kg ha^{-1}yr^{-1}. The general agricultural sources of low phosphorus stream inputs were associated with sandy soils, cereal crops, pasture and woodland. High phosphorus loadings were associated with clay soils and intensive row crops. Phosphorus in fertilizer and phosphorus related to manures and septic fields directly correlated to 10% to 50% of the total phosphorus in the stream loadings. An average of approximately 60% of the total phosphorus was organic and mineral forms carried with sediment particles. The erosion and transport of soil particles, with their associated natural and added phosphorus, made up the bulk of the total phosphorus load from farmland.

Beef feedlots appeared to represent the greatest potential for stream pollution from livestock sources in the Canadian Great Lakes basin.

The contribution of heavy metals from agricultural practices was negligible compared to contributions from natural geologic weathering processes and from other pollution sources (automobile exhaust, urban and industrial areas).

Pesticides were detected infrequently in streams. The pesticides were from accidental spills or careless cleaning of equipment or disposal of containers. Atrazine was the most frequently detected pesticide.

Nitrate did not appear to be a Great Lakes water quality problem. However, nitrate was found upstream in surface and groundwater, occasionally at levels exceeding the drinking water maximum of 10 mg/L. Excessive use of nitrogen fertilizer and inefficient management (e.g. poor timing of applications relative to crop needs, excessive cultivation and poor retention of nitrogen in the soil after crop uptake ceases) contributed to the high nitrate levels observed.

Title: Groundwater quality beneath small-scale, unlined earthen manure storage

Authors: Culley, J.L.B., and P.A. Phillips

Published: 1989

Source: Transactions of the ASAE. 32(4): 1443-1448

Study site: Central Experimental Farm, Ottawa, Ontario, Canada

Study period: 1982 to 1986

Description: Pairs of pits for earthen storage, each dug 1.5 m below grade and 10 m^3 in volume, were excavated at three locations. The soil type of site 1 was a

Dalhousie clay loam; site 2 was a Piperville sandy loam; and site 3 was a Mille Isle sand. The soils were not compacted. Soil water samples were taken from directly beneath the pits and below the berms at 1.75, 2.5 and 3.5 m below grade. Water samples were analyzed for nitrogen, phosphorus and minerals.

Findings: Inorganic N, P and mineral contents of water in clay of similar hydraulic conductivity were strongly affected by the properties of the overlying soil in which small-scale unlined earthen manure storage reservoirs were dug in acidic sand. Considerable increases in P were found, but no changes in inorganic N content were observed beneath clay loam storage. The concentrations of all parameters increased over the five-year period indicating that the small-scale storage reservoirs did not effectively seal during that period. Unlined earthen pits may not be efficient manure structures in Dalhousie clay loam, Piperville sandy loam and Mille Isle sand.

Title: Impact of agricultural practices on tile water quality

Authors: Fleming, R.J.

Published: 1990

Source: ASAE Paper no. 902028

Study site: Parkhill Creek watershed of southwestern Ontario, Canada. Agricultural land use covers almost the whole watershed (135 km^2).

Study period: 1986 to 1989

Description: Weekly water samples of 14 tile drains and six representative stream sites in the study watershed were analyzed for several physical, chemical and bacterial parameters.

Findings: The mean levels of nitrate and phosphorus were higher in the tile water than in the stream water (10.6 and 6.8 mg/L, respectively, for N; 1.3 and 0.14 mg/L for P). However, the faecal coliform levels were higher in the stream water than in the tile water (217 vs 78 per 100 mL). Five out of six stream sites had mean concentrations of total phosphorus exceeding the Ontario Ministry of the Environment's standard for total phosphorus in a stream. The source of the phosphorus seemed to be from the direct connection of milk house drains to the field tile drain system.

Nitrate levels in tile water were not necessarily related to manure use but appeared to be related to the total N applied to cropland, regardless of the source (fertilizer, manure, legume).

Faecal coliform levels in tile drain water varied widely from one farm to the next. Farms which had tiles draining areas around farmsteads and farms where manure was spread regularly onto the fields had the highest levels of faecal coliform bacteria in the tile drain water.

Title: Impact of continuous potato production on water quality

Authors: Madramootoo, C.A., K. Wlyo, P. Enright, and C. Bastien

Published: 1991

Source: Canadian Society of Agricultural Engineers Paper no. 91-108

Study site: Two tile drained potato cropped fields at St. Leonard d'Asron, Quebec, Canada

Study period: April to November, 1989 to 1990

Description: Tile drain flow from two fields was monitored over two growing seasons. Field 1 was 4.87 ha and Field 2 was 4.6 ha. The soil type was Ste. Jude sandy loam. Water samples, taken after each rainfall event, were tested for nitrogen, phosphorus, potassium (K) and metribuzin concentration.

Findings: Nitrate leaching to tile drains was a source of contamination of surface waters. Nitrate concentration in tile drain flow exceeded the Canadian drinking water maximum of 10 mg/L most of the time. The range of NO$_3$-N concentrations for the two fields was between 11.68 and 40.00 mg/L in 1989 and between 1.70 and 36.97 mg/L in 1990.

N, P and K concentrations in the tile drain flow varied throughout the growing season but were independent of the amount of tile drain flow or daily and monthly rainfall.

Metribuzin levels of up to 3.5 μg/L were found in the tile drain flow. In surface runoff samples, concentrations of 33 to 47 μg/L were measured. This is above the Environment Canada limit for aquatic life. It appeared that the herbicide was carried over from 1989 to 1990.

Title: Effects of potato production on groundwater quality: observations in New Brunswick, Canada

Authors: Milburn, P., C. Gartley, J. Richards, and H. O'Neill

Published: 1990

Source: Journal of Environmental Quality. 19(3): 448-454

Study site: Agricultural regions of New Brunswick, Canada

Study period: April 1987 to December 1988

Description: Flow volumes and NO$_3$-N concentrations of drain discharge from five systematically tile drained, commercial potato fields were measured to assess the potential for NO$_3$-N leaching associated with current production practices. The sites ranged from 3 to 10 ha and varied in fertilizer application rates, cropping practices, rainfall and duration of data collection. Ten site-years of data were collected.

Findings: A substantial portion of the private rural groundwater wells in two of the three agricultural regions sampled had NO_3-N concentrations in excess of 10 mg/L. The source of NO_3-N was nonpoint fertilizer-N and/or soil-N. Mean concentrations of NO_3-N in rural well waters were positively related to the intensity of agricultural production, particularly potato production.

There was no increase in mean NO_3-N concentrations of well water over 15 years; in one region mean NO_3-N concentrations declined with time. The stabilization or decline in NO_3-N concentrations appeared to be related to a combination of decreased potato production and correction of over-fertilization of N which occurred in the 1960s.

Title: Leaching of dinoseb and metribuzin from potato field in New Brunswick

Authors: Milburn, P., H. O'Neill, C. Gartley, T. Pollock, J.E. Richards, and H. Bailey

Published: 1991

Source: Canadian Agricultural Engineering. 33(2): 197-204

Study site: Potato fields of New Brunswick, Canada

Study period: April to December, 1987 and 1988

Description: Five study sites ranging from 3 to 10 ha were monitored for dinoseb and metribuzin in discharge from tile drains and shallow groundwater.

Findings: Dinoseb and metribuzin, when applied at the recommended rates, can leach from the root zone under soil and climate conditions common to potato production in New Brunswick.

Title: Ontario farm groundwater quality survey

Authors: Rudolph, D., H. Rudy, D. Gauvin-Walker, M. Goss, M. Hicknell, and G. Merchant

Published: 1992

Source: Ontario farm groundwater quality survey. Agriculture Canada, Agri-Food Development Branch, Guelph, Ontario

Study site: Ontario farm wells, predominantly in areas of intense agriculture

Study period: Fall and winter, 1991

Description: One-time samples of well water from 1,300 farm wells were analyzed for nitrate, several common herbicides, petroleum, and total and faecal coliform bacteria. One hundred and forty-four multi-level monitoring wells were installed in farm fields in areas of intense agricultural activity, predominantly in sandy, permeable soils. The monitoring wells were used to correlate groundwater quality beneath active farm fields and the occurrence of contamination in farm wells.

Findings: Thirty-seven percent of the farm wells contained one or more of the target contaminants at concentrations above the provincial drinking water objectives. Thirty-one percent exceeded the maximum for coliform bacteria, indicating contamination from surface runoff. Twenty percent contained faecal coliform bacteria, an indication of recent contamination from human or animal faeces. Coliform contamination increased with decreasing distance between feedlots and wells. Thirteen percent exceeded the drinking water maximums for nitrate (10 mg/L). Nitrate concentrations tended to be higher in areas with sandy, more permeable soils and more intensive annual cropping (corn and soybean rotations). Seven percent had concentrations of coliforms and nitrates at levels that increased the risk of blue-baby syndrome (methaemoglobinaemia). However, no cases of this disease have been reported in Ontario in at least 20 years. Eight percent of wells had pesticides at the detection level. Only one well in 1,300 had a herbicide level that exceeded Ontario drinking water maximums. This was due to a spill near the well. No contamination from petroleum was found. Older wells (>60 years) and shallow dug or bored wells were most commonly contaminated.

The multi-level monitoring well survey found 44% of the wells had nitrates above the maximum acceptable concentrations. In one group of 56 wells, 62% had total coliform bacteria levels above maximums, and 23% had faecal coliform bacteria in at least one of the monitoring levels. Pesticide residues were detected in 4% of the wells. The intensity of cultivated annual crop production (corn, soybean rotations) matched a higher frequency of contamination. Faecal contamination was more frequent where manure was applied.

Title: **Effects of livestock wastes and agricultural drainage on water quality: an Ontario case study**

Authors: Thornley, S., and A.W. Bos

Published: 1985

Source: Journal of Soil and Water Conservation. 40(1): 173-175

Study period: April 11 to November 22, 1983

Study site: South Branch of the Thames River, Ontario, Canada. This branch has a 230 km^2 (90 mi^2) watershed which contains more than 300 livestock farms that average 80 animal units per farm.

Description: Water quality was monitored in the river and along drainage systems near manure piles, barnyards, manured fields, tile drainage system outlets, and where cattle had access to the river. Water samples were analyzed for 13 chemicals and seven types of bacteria.

Findings: Both the bacterial and chemical characteristics of the underground drainage from barnyard and manure pile runoff were comparable in quality to domestic sewage. Because of the extent of artificial drainage and high farm animal densities, subsurface drainage outlets are major contributors to the poor water quality. Improper waste management is the cause of the poor water quality discharging from farm water sources.

1.5.3 Research in the United States

Title: Impact of agricultural drainage wells on groundwater quality

Authors: Baker, J.L., R.S. Kanwar, and T.A. Austin

Published: 1985

Source: Journal of Soil and Water Conservation. 40(6): 516-520

Study site: North central Iowa, U.S.A.

Study period: 1981 to 1982

Description: Monitoring of water quality draining from row-cropped areas into four drainage wells and farm water supply wells.

Findings: Concentrations of nitrate in all samples averaged 16 mg/L, and 85% of the samples exceeded 10 mg/L. The survey of farm well water quality showed that nitrate concentrations were higher where drainage wells were within 2 km of farm wells. Many of the farm wells with elevated concentrations were near drainage wells and in areas that had 15 m or more of overburden. This is strong evidence that the nitrate in the recharge to the drainage wells, rather than the nitrate in surface infiltration, had increased the nitrate concentrations in the aquifer.

Title: The effect of cattle grazing on indicator bacteria in runoff from a Pacific Northwest watershed

Authors: Jawson, M.D., L.F. Elliott, K.E. Saxton, and D.H. Fortier

Published: 1982

Source: Journal of Environmental Quality. 11(4): 621-627

Study site: Pacific Northwest watershed, Washington, U.S.A.

Study period: 1976 to 1979

Description: A 21.5 ha grazed watershed and a 0.9 ha ungrazed (control) watershed in the Pacific Northwest were monitored for indicator bacteria. Stream flow during runoff events was sampled hourly; for some events, runoff samples were obtained at several points within the grazed watershed.

Findings: Prolonged absence of grazing animals did not seem to affect the number of total coliform and faecal streptococcus in runoff from the nongrazed watershed. Each spring after a period of warm weather and prolonged absence of animals, there were increases in numbers of total coliform faecal coliform, and faecal streptococcus in the runoff. There was some correlation between recentness of grazing and numbers of indicator bacteria in runoff.

Present faecal coliform recommendations developed for point-sources would not apply adequately to grazed land in the Pacific Northwest. Indicator bacteria as presently analyzed would not provide a basis for developing Best Management Practices.

Title: Nonpoint source pesticide contamination of shallow groundwater

Authors: Kimball, C.G., and J. Goodman

Published: December 1989

Source: ASAE meeting presentation, Paper no. 89-2529

Study site: South Dakota, U.S.A.

Study period: Initiated in 1985, to be continued to December 1991

Description: Groundwater samples from seven field sites were analyzed for pesticides commonly used in the area.

Findings: Under dryland farming of row crops, small grain, soybeans and corn rotations, pesticide contamination was detected. More than 90% of the detected contaminants were herbicides. Lasso (alachlor) and 2,4-D were the most common herbicides detected. Concentrations of 2,4-D did not approach the EPA's drinking standard of 100 mg/L. Fifty percent of the samples had concentrations of alachlor greater than Wisconsin's standard of 0.15 mg/L.

Pesticide detections were most frequent during or immediately following application and appeared to be short lived or sporadic in terms of their occurrence in groundwater. The most common length of time between application and detection was one month. Eighty-four percent of the detections were one-time events with no detection the following month.

Title: Impacts of agricultural chemicals on groundwater quality in Iowa

Authors: Libra, R.D., G.R. Hallberg, and B.E. Hoyer

Published: 1987

Source: Pages 185-215 *in* D.M. Fairchild, ed. Groundwater quality and agricultural practices. Lewis Publishers.

Study site: Big Spring Groundwater Basin, northeast Iowa, U.S.A.

Study period: 1982 to 1984

Description: An extensive database was developed, defining hydrogeology, soils and land use in the basin.

Findings: The delivery of nitrate (and other surface-derived contaminants) to groundwater was largely controlled by the timing and volume of groundwater. Annual NO_3-N losses from the basin were a function of water flux. Thirty-three to thirty-five percent of the fertilizer-N applied was lost to surface water and groundwater annually. The losses were in direct response to the large amount of fertilizer applied.

Nitrate concentrations in groundwater between 1951 and 1968 averaged 2.7 mg/L and between 1982 and 1984 averaged 9.0 mg/L, a three-fold increase. This directly paralleled the increase in N applications from fertilizer and manure in the basin.

Where sufficient thickness of low permeability materials protected underlying aquifers, agricultural contaminants were still leaching to groundwater, but this shallow groundwater generally moves laterally, discharging to streams, rather than vertically to aquifers used for drinking water sources.

Title: Nitrogen and phosphorus losses in runoff from no-till soybeans

Authors: MacDowell, L.L., and K.C. McGregor

Published: 1980

Source: Transactions of the ASAE. 23(3): 643-648

Study site: North Mississippi Agricultural and Forestry Experiment Station, Holly Springs, Mississippi, U.S.A.

Study period: 1972 to 1973

Description: Runoff and soil loss were monitored from no-tillage and conventional tillage soybean fields with various fertilizer rates. Runoff was analyzed for nitrogen and phosphorus concentrations.

Findings: No-tillage effectively reduced soil and associated nutrient losses. Over the two-year period, the average annual soil loss from no-tillage soybeans was only 0.3 metric tons per hectare (t/ha) as compared with 29 t/ha from conventional tillage. Total N and P losses from no-tillage soybeans in 1973 were only 4.7 and 2.8 kg/ha, respectively, as compared with 46.4 and 17.6 kg/ha from conventional tillage.

No-tillage increased soluble P concentrations and losses in runoff. Soluble P concentrations were related to crop management practices and increased in the following order: conventional tillage soybeans (continuous) < no-tillage corn-soybeans (rotation) < no-tillage soybeans (continuous) < no-tillage soybeans-wheat (double-cropped). The mean soluble P concentration in runoff from no-tillage soybeans was 0.40 mg/L, as compared with 0.02 mg/L from conventional tillage soybeans receiving the same amount of phosphate fertilizer but with more incorporation into the soil at planting.

Where applicable, no-tillage is a Best Management Practice for reducing potential nonpoint pollution by sediment and total plant nutrients in surface runoff from agriculture.

Title: Nutrient loss via groundwater discharge from small watersheds in southwestern and south central Wisconsin

Authors: Mason, J.W., G.D. Wegner, G.I. Quinn, and E.L. Lange

Published: 1990

Source: Journal of Soil and Water Conservation. 45(2): 327-330

Study site: Ten small streams in south central and southwestern Wisconsin, U.S.A.

Study period: 1988 to 1989

Description: Nitrogen and phosphorus levels in the base flow discharge of 10 streams were measured and compared to historical data on the same streams.

Findings: Nitrate concentrations had increased significantly in three streams. The changes appear to be related to agricultural activities and fertilizer use in the watersheds. The highest nitrate levels were found in the area south of the Wisconsin River where land use changes have occurred. Current P levels in the 10 streams were established, but trends could not be determined because of the unreliability of the historical data set.

Title: Maize production impacts on groundwater quality

Authors: Schepers, J.S., M.G. Moravek, E.E. Alberts, and K.D. Frank

Published: 1991

Source: Journal of Environmental Quality. 20(1): 12-16

Study site: Central Platte Natural Resource District in Nebraska, U.S.A.

Study period: 1988

Description: Groundwater quality was monitored and fertilizer use was recorded.

Findings: Fields where producers exceeded fertilizer N recommendations also had the highest groundwater NO_3-N concentrations.

Title: Phosphorus variations in surface runoff from agricultural lands as a function of land use

Authors: Wendt, R.C., and R.B. Corey

Published: 1980

Source: Journal of Environmental Quality. 9(1): 130-136

Study site: White Clay Lake watershed near Cecil, Wisconsin, U.S.A.

Study period: June 1976 to July 1977

Description: Twenty plots were studied for the effects of land use, time of year and application of animal manure on several forms of phosphorus in runoff from farmed and forested lands.

Findings: Loss of P from forest land was less than from crop land. The greatest losses of potentially available P in runoff occurred on recently tilled soils and on row crops associated with the highest sediment loads. Losses of dissolved molybdate-reactive P (most of which is dissolved orthophosphate) were greatest from established or newly seeded alfalfa fields in the fall after the foliage had been killed by frost.

Surface applied manure did not appear to greatly increase the pollution potential from rainfall runoff on unfrozen soil. However, the effect of surface applied manure on P loads in runoff from frozen soil was less clear and may pose a water quality hazard under certain conditions.

1.6 EXTRAPOLATING TO NONPOINT POLLUTION PROCESSES IN ALBERTA

Changes in water quality indicators such as bacterial counts, pesticide residues, sediment loads, heavy metals, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and dissolved chemical concentrations in groundwater and surface water, have been linked to agricultural practices such as tillage, continuous cropping, use of pesticides, and spreading of manure and chemical fertilizers (Phillips et al. 1981).

Sediment loadings by erosion processes have been identified as the major transport medium for phosphorous and trace elements to surface waters (Coote and MacDonald 1978; Andraski et al. 1985).

In southern Alberta's semi-arid climate, rainfall on wet soil or excessive irrigation can cause erosion of soil particles and loss of soluble chemicals by surface runoff. The impact of soil erosion by water, particularly the selective removal of nutrients, will be greater on residual soil fertility than on surface water quality in the southern prairie region of Canada (Beke et al. 1989).

Many factors affect the transport of pesticides by runoff and their movement through the soil profile. These factors include land use, soil type, tillage, amount of crop residue, time of application, rainfall characteristics and pesticide characteristics such as persistence, solubility, volatility and adsorptivity.

The absence of tillage will generally favour the formation of macropores and channels, the continuity of which is not disturbed by plowing. Macropores and reduced runoff could permit an acceleration of downward water movement and thus increase pesticide and nitrate leaching to tile drains or groundwater (Masse et al. 1991; Kramer et al. 1989). Atrazine, alachlor, cyanazine and metribuzin seem to move preferentially through macropores to groundwater after heavy rainfall events (Kanwar et al. 1991). Gish and Helling (1989) found that, with atrazine and cyanazine, the greatest threat to groundwater is immediately after application, regardless of tillage. The amount of crop residue left on or incorporated into the soil may also affect pesticide movement (Kenimer et al. 1986).

Monitoring of groundwater in Alberta and elsewhere has shown the persistence and mobility of certain pesticides (Rodvang and Riddell 1992). Some pesticides (picloram (Smith et al. 1988)) are able to persist in a field beyond the year of application. Some pesticides (dicamba, mecoprop, MCPA and 2,4-D (Rodvang and Riddell 1992)) have been detected in fields adjacent to the field where they were applied.

Several studies link NO_3-N concentrations increases in groundwater to fertilizer use. In Iowa, nitrate in groundwater tripled from 1951 to 1968 along with estimates of fertilizer and manure application on cropland (Libra et al. 1987). In New Brunswick, NO_3-N concentrations in rural groundwater wells were related to the intensity of agricultural production (Milburn et al. 1990). Nitrate concentration in three Wisconsin streams was linked to agricultural activities and fertilizer use (Mason et al. 1990). In Nebraska, the fields where producers exceeded fertilizer N recommendations also had the highest groundwater NO_3-N concentrations (Schepers et al. 1991).

The most likely potential sources for agricultural nonpoint water pollution in Alberta appear to be uncontrolled access of cattle to streams, uncontrolled feedlot runoff, spreading of manure on cropland, and intensification of agriculture in irrigated areas. Currently, livestock operations do not present a serious problem (Goatcher et al. 1991). There is some evidence suggesting overapplication of manure on sandy soils can result in NO_3-N contamination of shallow groundwater (Chang et al. 1991). Studies in southern Alberta indicate that irrigation is not degrading water quality at present (Bolseng 1992a, 1992b, 1992c). The potential for pollution from these sources will increase as operations intensify, as shown in other parts of North America.

Agricultural activities can and do affect Alberta's water resources but serious water quality degradation due primarily to agriculture has not been found to date. Water quality monitoring in Alberta is ongoing to determine if there are long-term changes in water quality which can be linked to agricultural practices.

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2.0 BEST MANAGEMENT PRACTICES

2.1 INTRODUCTION

Prevention of water pollution from agricultural sources is much more cost-effective than attempting to restore polluted waters to pristine conditions. Recent results from field studies in the United States have identified Best Management Practices (BMPs) for controlling sediment, pesticide, salt, nutrient and microorganism pollution of surface waters. BMPs include practices for feedlot and cow/calf operations, fertilizer and pesticide management, irrigation and manure handling.

2.2 BEST MANAGEMENT PRACTICES LITERATURE SUMMARY

2.2.1 Evaluation of Best Management Practices on Rural Clean Water Program Projects

This section provides summaries of several projects in the United States' Rural Clean Water Program (RCWP), one of the most successful federal water quality programs, based on a comprehensive evaluation (Gale et al. 1992). Under the RCWP, various BMPs were implemented on a total of 21 watersheds affected by agricultural pollution. Over half of the impaired water bodies showed water quality improvements during the study period. The National Water Quality Evaluation Project at North Carolina State University served as a technical support team for these RCWP projects, performing technical evaluations of projects, analyzing NPS pollution abatement progress, and providing technical assistance on monitoring and data analysis systems. Each project summary includes the pollutants mitigated, the implemented BMPs and the results of implementation.

Project: Lake Tholocco (RCWP 1), Alabama

Impaired resource type: Lake

Pollutant(s) mitigated: Faecal coliform bacteria and sedimentation

Source of pollutant(s): Swine waste and erosion

Agricultural activities: Cropland (corn and peanuts) and some livestock operations.

Implemented BMPs:
1. Terraces
2. Soil conservation systems

Effectiveness of BMPs: Faecal coliform levels decreased significantly, which made resumption of contact-body water sports in Lake Tholocco possible. Although never measured, sediment loads appeared to be decreasing, and fish populations appeared to be increasing.

Project: Rock Creek (RCWP 3), Idaho

Impaired resource type: Streams and irrigation canals

Pollutant(s) mitigated: Nutrients (phosphorus and nitrogen)

Source of pollutant(s): Irrigation tract erosion

Agricultural activities: Irrigated pasture, cropland and rangelands

Implemented BMPs:

1. Sediment retention structures
2. Irrigation water management
3. Vegetative filter strips
4. Cover crops
5. Conservation tillage
6. Animal waste management

Effectiveness of BMPs: Delivery of sediment and phosphorus to the Snake River decreased by 75% and 68%, respectively.

Project: Prairie Rose Lake (RCWP 5), Iowa

Impaired resource type: Lake, within state park with agricultural watershed

Pollutant(s) mitigated: Sediment

Source of pollutant(s): Cropland erosion

Agricultural activities: Cropland

Implemented BMPs:

1. Management and structural sediment control
2. Animal waste controls
3. Fertilizer management
4. Pesticide management

Effectiveness of BMPs: Water clarity was highest in 1982-83, following draining of the lake. Since then, clarity has deteriorated to pre-RCWP levels. Reduction in sediment delivery due to adoption of conservation practices may have improved water clarity, but algal density has increased, apparently because of greater light penetration. Recreational users perceive water quality improvement, although monitoring data cannot confirm this.

Strong leadership within the farm community and positive relationships between the park ranger and landowners resulted in a 92% voluntary participation rate in BMP changes.

Project: Bayou Bonne Idee (RCWP 7), Louisiana

Impaired resource type: Stream

Pollutant(s) mitigated: Pesticides and eroded sediments

Source of pollutant(s): Large, relatively flat cotton fields

Agricultural activities: Intensive cropping

Implemented BMPs:

1. Permanent vegetative cover
2. Conservation tillage systems
3. Improved irrigation and/or water management system

Effectiveness of BMPs: Trend analysis indicated slight decreases in turbidity, total suspended solids and total phosphorous over the project period; however, these decreases were not statistically significant or specifically linked to land treatment.

Project: Snake Creek (RCWP 11), Utah

Impaired resource type: Reservoir

Pollutant(s) mitigated: Phosphorous and bacteria

Source of pollutant(s): Dairy waste

Agricultural activities: Livestock operations with crops of alfalfa, small grains (barley, wheat and oats), and pasture to support the livestock

Implemented BMPs:

1. Animal waste management systems
2. Grazing land protection
3. Stream protection
4. Improvements in water management

Effectiveness of BMPs: Monitoring data showed declines in phosphorus and coliform levels in Snake Creek.

Project: Tillamook Bay (RCWP 18), Oregon

Impaired resource type: Estuary

Pollutant(s) mitigated: Faecal coliform bacteria

Source of pollutant(s): Dairy waste

Agricultural activities: Agricultural lands (pasture, hay, silage) cover 23,540 ac (9530 ha) of the project watershed. Dairy herds occupy lowlands along the bay.

Implemented BMPs: Manure storage and management

Effectiveness of BMPs: Reduction in bacteria contamination of oyster beds in the bay, resulting in the reopening of shellfish beds to commercial and recreational harvesting.

Project: Oakwood Lakes - Poinsett (RCWP 20), South Dakota

Impaired resource type: Lakes and groundwater

Pollutant(s) mitigated: Nutrients and pesticides

Source of pollutant(s): Cropland and animal waste

Agricultural activities: Cropland (corn, soybeans and small grains) and small livestock feeding units

Implemented BMPs:

1. Conservation tillage
2. Fertilizer management
3. Pesticide management
4. Animal waste management systems

Effectiveness of BMPs: Reduction of sediment entering the lakes, but little improvement of surface and ground water quality.

2.2.2 Best Management Practices for Pesticides, Fertilizers and Feedlots

Problem to be mitigated: Contamination by pesticides

Information source: Jacobsen, J.S., and G.D. Johnson. 1989. Water Quality and Agrichemicals in Montana. Montana State University, Extension Service, Bozeman, Montana. 59717. 12 p.

Recommended BMPs:

1. Use integrated pest management.
2. Consider soil characteristics and geology of the area.
3. Select pesticides with the least potential for leaching into groundwater.
4. Read and follow pesticide label directions.
5. Calibrate and maintain application equipment.
6. Measure and mix pesticides properly.
7. Avoid back-siphoning from sprayer tanks into wells.
8. Mix chemicals at least 30 m away from water sources. *Never mix chemicals directly uphill from a water source.*
9. Properly dispose of wastes.
10. Store pesticides away from water sources.
11. Delay application of pesticides after heavy rain, sustained rain or wind, and when irrigation is planned.

Problem to be mitigated: Contamination by pesticides

Information source: Anonymous. 1992. Groundwater Protection. Canadian Farming. Spring: 20-21. Quoting Lyn Kirschner, Conservation Technology Information Center, West Lafayette, Indiana.

Recommended BMPs:

1. Read and follow the chemical label. Do not use rates higher than labelled.
2. Mix chemicals at least 30 m away from wellheads, ditches, streams or other water sources.
3. Avoid back-siphoning of chemical by using an anti-back flow valve and by keeping the discharge end of fill hoses above the tank's water level or use a "water only" nurse tank in the field to deliver water to spray tanks. Keep spray tanks away from water sources.
4. Use chemicals only when necessary. Scout for weeds, insects and diseases in the crops.
5. Calibrate sprayers at the beginning of each cropping season and as needed throughout the season.
6. Estimate the number of acres to be treated before spraying, and mix only the amount of chemical you need to treat that acreage.
7. Triple rinse or pressure rinse chemical containers before disposing and return the rinse water to the spray tank to be applied to the crop.
8. Establish and maintain grass filter strips around the edges of fields to slow runoff.
9. Leave at least a 30% cover of crop residue on cropland or plant a cover crop to prevent loss of soil that may contain pesticides.
10. Build berms or diversions around sinkholes to prevent runoff from entering directly into groundwater.
11. Leave "no-spray" strips around open water, wellheads, sinkholes and irrigation ditches.

Problem to be mitigated: Contamination by fertilizers

Information source: Jacobsen, J.S., and G.D. Johnson. 1989. Water Quality and Agrichemicals in Montana. Montana State University, Extension Service, Bozeman, Montana. 59717. 12 p.

Recommended BMPs:

1. Select a realistic yield potential.
2. Test the soil before fertilizing or planting.
3. Allow credit for nutrient contributions from manure, sludge, organic matter, irrigation water and legumes.
4. Select an appropriate N fertilizer source.
5. Use a split application of N fertilizer.
6. Test plant tissues for nutrient requirements.
7. Time fertilizer applications and place fertilizer for maximum plant use.
8. Calibrate the fertilizer applicator.
9. Use a nitrification inhibitor.
10. Match irrigation amounts to crop demand, environmental conditions and soil water holding capabilities to minimize water percolation and nutrient leaching.
11. Blend fertilizers away from water sources.

12. Store fertilizer materials properly.

Problem to be mitigated: Contamination by nutrients and sediment from beef cattle operations (animal wastes)

Information source: Serecon Management Consultants. 1992. Environmental risk assessment for the Alberta beef cattle industry. Alberta Cattle Commission, Calgary, Alberta. 31 p.

Recommended BMPs: For feedlots:

1. Properly site and construct feedlots.
2. Use feedlot continuously or clean feedlot promptly after livestock are removed. Intermittent stocking of feedlots (i.e. pens left empty part of the year) results in less compaction of the pens' surface soils and more potential for infiltration of manure laden water.
3. Develop a well defined system of dikes to divert runoff from entering the feedlot.
4. Develop a well defined drainage ditch system to move surface runoff from pens to a retention pond. Pond must be adequately sized and located in a dead-end basin on impermeable soils.

For cow/calf operations:

1. Prevent direct access to water sources (streams, rivers, lakes, dugouts).
2. Reduce concentration of animals.
3. Provide alternative water sources away from the edges of water bodies.
4. Fence parts of or all banks of water bodies.

Problem to be mitigated: Contamination by microorganisms, nitrate-nitrogen and phosphorus from livestock and poultry wastes

Information source: Arnold, J., and E. van Donkersgoed. 1992. C. Brown, H. Cuthbertson, H. Fraser, D. Hillborn, K. Reid, and R. Stone (OMAF), eds. Best Management Practices: livestock and poultry waste management. Agriculture Canada and Ontario Ministry of Agriculture and Food. Woodstock, Ontario. 49 p.

Recommended BMPs: For manure storage:

1. Use properly sized, sited and constructed manure storage facilities.
2. Divert uncontaminated water (rain, snowmelt, runoff) from manure storage areas.
3. Divert contaminated liquids (livestock housing wash water, silo seepage, exercise yard runoff, solid manure pile runoff) into separate runoff storage.

For manure spreading:

1. Test soil and manure nutrient content regularly.
2. Maintain equipment.
3. Apply only enough manure to meet the crop's nutrient needs.
4. Do not apply manure on snow or frozen ground, flood-prone areas or

sloped hay land near watercourses.
5. Do not spread liquid manure within 10 m of an open watercourse.
6. Do not spread solid manure within 5 m of an open watercourse.
7. In general, apply manure before and early in the growth cycle of a crop. Some row crops can have manure applied as a side dressing after early growth.
8. Delay spreading manure on wet soils to avoid soil compaction caused by heavy equipment. If using irrigation to spread manure, time irrigation to avoid excessively wet or dry soils.
9. Incorporate the manure into the soil as soon as possible after spreading.
10. Till over tile drain areas before applying liquid manure in the late summer or early fall.
11. Monitor tile outlets before, during and up to a day after application for any visible signs of manure. If there are signs of manure in the runoff, plug the drains.

2.2.3 Other Best Management Practices

Problem to be mitigated: Contamination from eroded sediment, animal wastes, nutrients, fertilizers and pesticides

Information source: Ritter, W.F. 1992. Reducing impacts of nonpoint source pollution from agriculture: a review. Journal of Environmental Science and Health: Part A, A23(7): 645-667.

Recommended BMPs: For erosion and sedimentation:

1. Conservation tillage systems
2. Contour farming
3. Cover crops
4. Diversions
5. Grassed waterways
6. Crop rotation
7. Sediment basins
8. Stream bank protection and stream channel stabilization terraces
9. Filter strips

For disposal of animal wastes:

1. Apply to land as a fertilizer and soil conditioner.
2. Apply to land as supplemental water for crop production.
3. Reuse liquids to flush and transport manure.
4. With manure liquid/solid separation systems, reuse processed solids as bedding or litter.
5. Use as a supplemental energy source (manure digestor systems producing methane).
6. Reuse as a feed for livestock (poultry wastes used as a urea supplement for cattle feed).

For unconfined animal production:

1. Adopt an effective erosion control program.
2. Tailor grazing programs and stocking rates to the local microclimate, soil, vegetation, topography and geology.

3. Locate animal holding pens or high density grazing away from streams.
4. Maintain grass cover downslope from sites where animals congregate and along stream banks to provide a vegetative filter.

For feedlots:

1. Locate the facility away from a stream or drainage channel.
2. Divert outside runoff away from the feedlot surface using diversion terraces and roof gutters
3. Collect solids carried off the feedlot surface by runoff. Solids should be settled out in channels, debris basins or grassed waterways where they can be removed and disposed of properly on land.
4. On small feedlots close to water bodies, install a grass filter strip to improve runoff quality before it enters the water. The strip should be at least twice as large as the feedlot.
5. Install a runoff holding pond on large feedlots if the water quality risk is high and on small feedlots if the location prevents the use of a vegetative filter. The holding pond should have a settling basin, and the collected runoff should be disposed by irrigation on nearby crop or pasture land.
6. Apply manure to cropland to make best use of the manure's nutrients.

For manure application:

1. Test soils to identify nutrient needs.
2. Analyze manure to determine composition.
3. Avoid applying excess nutrients.
4. Time manure applications relative to crop and season of the year.

For nitrogen and phosphorus losses:

1. Test soils.
2. Use proper application rates. Nitrogen and phosphorus application rates should not exceed the assimilative capacity of the crop.
3. Use erosion control BMPs.
4. Use split applications of nitrogen (rather than a single application) to reduce the amount of leachable nitrogen.
5. Use legume crops for green manuring (plowdown).
6. Incorporate surface applied nitrogen.

For pesticides:

1. Use erosion control BMPs.
2. Use alternative pesticides. Where more than one pesticide is available to control a specific weed or pest, use the pesticide with low toxicity and persistence.
3. Optimize pesticide placement to reduce losses (i.e. banding versus broadcast).
4. Rotate crops to reduce pest infestations.
5. Use proper pesticide formulation. Granular applications if incorporated in to the soil can be preferable to liquid formulations. Surfactants increase the penetration and translocation of the pesticide in the target plant.
6. Use integrated pest management.

Problem to be mitigated: Contamination by nutrients, pesticides and salts in surface water and groundwater

Information source: Logan, T.L. 1990. Agricultural Best Management Practices and groundwater protection. Journal of Soil and Water Conservation. 45(2): 201-206.

Recommended BMPs: For surface water, structural options:
- Terraces, interceptor ditches on hillsides
- Grassed waterways
- Subsurface (tile) drains, water table management
- Irrigation systems
- Sediment and water retention basins
- Manure storage, runoff control, filter strips
- Irrigation tailwater recovery systems

For surface water, cultural options:
- Conservation tillage
- Contour cropping, strip cropping, contour strip cropping
- Cover crops
- Crop rotation
- Subsoiling
- Critical area planting
- Stream bank protection

For surface water, management options:
- Low-input farming management
- Integrated pest management
- Animal waste management
- Fertilizer management
- Pesticide management
- Irrigation management

For groundwater, structural options:
- Subsurface (tile) drains, water table management
- Irrigation systems
- Chemigation back-siphon prevention devices
- Surface drains
- Manure storage facilities

For groundwater, cultural options:
- Cover crops
- Critical area planting

For groundwater, management options:
- Low-input farming management
- Integrated pest management
- Animal waste management
- Fertilizer management
- Pesticide management
- Irrigation management
- protection of sensitive groundwater recharge areas

Problem to be mitigated: Salinity from irrigation

Information source El-Ashry, Mohamed T., Jan van Schilfgaarde, and Susan Schiffman. 1985. Salinity pollution from irrigated agriculture. Journal of Soil and Water Conservation. 40(1): 48-52.

Recommended BMPs: For irrigation water application efficiency:

1. Schedule irrigation.
2. Use flow measurement and water measurement devices.
3. Install water-efficient equipment.
4. Use land levelling.
5. Modify crop management (e.g. special tillage practices and seed bed preparation).
6. Plant salt-tolerant crops.

For disposal of saline agricultural return flows or desalination of saline drainage water:

1. Reuse drainage water if not excessively salty.
2. Dispose of highly saline return flows in deep wells or evaporation ponds, or export return flow from the basin.

Reduce water loss from seepage through conveyance systems by lining canals, ditches and laterals with concrete, asphalt or plastic.

Problem to be mitigated: Salinity from irrigation and from dryland sources

Information source: Kruse, E.G., J. Ayers, W. Evans, A. Halvorson, J. Hedlund, J.L. Thomas, and L. Willardson. 1989. Irrigation and drainage practices. Pages 75-84 *in* Proceedings from the National Water Conference, American Society of Civil Engineers. New York, NY.

Recommended BMPs: For irrigated cropland, water delivery improvement:

- Canal lining
- Ditch replacement with pipelines
- Land levelling

For irrigated cropland, irrigation improvement:

- On-farm irrigation automation
- Change of irrigation method
- Irrigation scheduling
- Uniform irrigation design

For irrigated cropland, better drainage:

- Installation of drains in naturally poorly drained soil
- Interceptor drains installed perpendicular to subsurface flow, upstream of land to protect and collect excess lateral flow in soils with shallow impermeable layers
- Installation of relief drains to remove water directly from rainfall and irrigation

For irrigated cropland, disposal of drainage effluent:
- Evaporation ponds
- Use and reuse of effluent

For dryland seep problems, management of recharge areas:
- Planting of crops that will use excess water (alfalfa interceptor crops)
- Draining ponded surface water
- Intercepting lateral flow of subsurface water before it surfaces

2.2.4 Research on Best Management Practices

A. BMPS for Fertilizer and Manure

Title:	**Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields**
Authors:	Kanwar, R.S., J.L. Baker, and D.G. Baker
Published:	1988
Source:	Transactions of ASAE. 31(2): 453-461.
Study site:	Agronomy and Agricultural Engineering Research Centre near Ames, Iowa, U.S.A.
Study period:	1984 to 1986
Description:	Subsurface drainage water and shallow water tables below the root zone were analyzed for nitrates to determine the effects of no-tillage and conventional tillage, and single and split N-fertilizer applications for continuous corn production.
Evaluation of BMPs:	Over the three years of continuous, fertilized corn, the average NO_3-N concentrations in drainage waters increased from an average of 11 mg/L to 15 mg/L. NO_3-N concentrations for conventional tillage were greater than for no-tillage. NO_3-N concentrations were lower for split N applications at the reduced rate of 125 kg/ha (applied over the growing season) than for the single application at the higher rate of 175 kg/ha.

Title:	**Phosphorus losses as affected by tillage and manure application**
Authors:	Mueller, D.H., R.C. Wendt, and T.C. Daniel
Published:	1984
Source:	Soil Science Society of America Journal. 48(4): 901-905.
Study site:	Wisconsin, U.S.A.

Study period: Growing seasons of 1978 and 1979

Description: Simulated rainfall was used to compare soil and water losses among conventional, chisel and no-tillage systems for corn both with and without surface-applied manure prior to tillage.

Evaluation of BMPs: Manured no-tillage treatments had higher losses of algae-available P (AAP) and dissolved molybdate-reactive P (DMRP) than any other treatments. AAP losses from chisel sites were lower than losses from the no-tillage sites largely because runoff from the former was significantly less. Injecting the manure would appear to be a better method of application for no-tillage. Because of the potential reductions in runoff and P losses, surface spreading manure prior to chisel plowing is an effective method of disposing of animal wastes.

Title: Corn silage yield, shallow groundwater quality and soil properties under different methods and times of manure application

Authors: Patni, N.K., and J.L.B. Culley

Published: 1989

Source: Transactions of ASAE. 32(6): 2123-2129.

Study site: Animal Research Centre Farm near Ottawa, Ontario, Canada

Study period: May 1982 to 1985

Description: Shallow groundwater samples collected at a depth of 1.2 m near the centre of each study plot were analyzed for nitrate and ammonia. The plots were subjected to different methods of tillage and fertilizer placement (fall plowing, spring disking, sidedress injection, sidedress surface) and times of manure application.

Evaluation of BMPs: Regardless of the type of treatment, nitrate concentrations in shallow groundwater under the experimental plots were always greater than the recommended 10 mg/L for drinking water. Manure and fertilizer were applied at agronomically recommended rates.

Title: Bacterial quality of runoff from manured and non-manured cropland

Authors: Patni, N.K., H.R. Toxopeus, and P.Y. Jui

Published: 1985

Study period: April 1972 to November 1975

Source: Transactions of the ASAE. 28(6): 1871-1877.

Study site: Research Farm of the Animal Research Centre, Agriculture Canada, near Ottawa, Ontario, Canada

Study period: April 1972 to November 1975

Description: Non-snowmelt runoff from adjacent manured and non-manured watersheds was monitored for indicator bacteria concentrations.

Evaluation of BMPs: The potential for bacterial pollution of runoff due to manure plowdown appears to be greater if relatively fresh manure is used rather than long-term stored manure. Runoff from the fields with relatively fresh manure had much higher indicator bacteria counts.

The potential for bacterial pollution of cropland runoff due to manure plowdown of long-term stored manure is not much different from that when no manure is used. Faecal bacteria are almost always present in runoff from non-manured cropland, presumably because of the presence of wildlife on such land.

Title: Pollution potential and corn yields from selected rates and timing of liquid manure applications

Authors: Phillips, P.A., J.L.B. Culley, F.R. Hore, and N.K. Patni

Published: 1981

Source: Transactions of the ASAE. 24(1): 139-144.

Study site: Central Experimental Farm, Ottawa, Ontario, Canada

Study period: 1973 to 1979

Description: Surface and subsurface water from 14 plots was analyzed for nitrogen, phosphorus and potassium under different rates and times of liquid manure application and chemical fertilizer application and under no fertilizer application.

Evaluation of BMPs: Manure applied in winter on snow covered ground has a higher potential to pollute surface water than spring, fall and spring-fall applications. The higher the rate of winter application, the higher the nutrient concentrations in surface water. No relationship was found for non-winter application schedules.

Non-winter applications rates at and above 560 kg $ha^{-1}yr^{-1}$ of N manure could lead to water quality impairment. At this rate, soluble orthophosphorous concentrations tend to increase in tile drain effluent.

Title: Dissolved inorganic nitrogen and phosphate concentrations in discharge from two agricultural catchments in eastern Ontario

Authors: Phillips, P.A., J.L.B. Culley, F.R. Hore, and N.K. Patni

Published: 1982

Source: Agricultural Water Management. 5: 29-40.

Study site: Animal Research Centre Greenbelt Farm near Ottawa, Ontario, Canada

Study period: 1972 to 1976, 1979

Description: Two agricultural catchments with commonly used agricultural rotations (hay to maize using liquid manure and maize to alfalfa using chemical fertilizer) were monitored for changes in inorganic nitrogen and phosphorus concentrations in subsurface drain discharge. Nutrient concentrations were also monitored in the shallow groundwater beneath the crop receiving dairy cattle liquid manure.

Evaluation of BMPs: Annual applications of dairy manure in excess of 500 kg ha^{-1}year^{-1} applied to maize-cropped land resulted in gradually increasing NO_3-N concentrations in shallow groundwater down to 3 m in depth. Subsurface tile drainage from this catchment and from another larger catchment which was maize-cropped with chemical fertilizer at the recommended rates had higher NO_3-N concentrations which exceeded the Canadian drinking water limit of 10 mg/L. When chemically fertilized maize was replaced by alfalfa in the large catchment, NO_3-N concentrations decreased to less than 10 mg/L within one to two years.

Phosphate losses in subsurface drainage waters accounted for less than 1% of P inputs. Average NO_3-N losses from manured and chemically fertilized clay loam catchments were more than 10% of annual inputs. Losses of NO_3-N from the fertilized basin were considerably greater than those from the manured basin when expressed as percentages of N inputs.

Title: Lysimeter study of nitrogen fertilizer and irrigation rates on quality of recharge water and corn yield

Authors: Prunty, L., and B.R. Montgomery

Published: 1991

Source: Journal of Environmental Quality. 20: 373-380.

Study site: Corn fields in southeast North Dakota, U.S.A.

Study period: 1985 to 1988

Description: Four large drainage lysimeters were used to collect groundwater from an irrigated corn field. Different rates of N-fertilizer and irrigation water were applied to the crop. Water samples were analyzed for nitrate concentrations.

BMPs recommended: For this soil and climate, irrigation and N management can be tailored to produce nitrate concentrations below 10 mg/L with continuous corn. A low rate of N (75 kg/ha) produced a satisfactory yield (10.8 Mg/ha) while meeting the 10 mg/L limit in its drainage water. The yield was 1 Mg/ha less than the yield for the N rate of 125 kg/ha. The yield difference still makes it economically advantageous to fertilizer at the higher rate even though clearly higher nitrate levels in drainage water would result.

Title: Nitrogen leaching as influenced by nitrogen management and supplemental irrigation level

Authors: Timmson, D.R., and A.S. Dylla

Published: 1981

Source: Journal of Environmental Quality. 10(3): 421-426.

Study site: Herman Rosholt Bonanza Valley Irrigation Research Farm, near Westport, Minnesota, U.S.A.

Study period: 1974 to 1978

Description: The following six corn management systems were evaluated:

a. no fertilizer, no irrigation,
b. granular N fertilizer, no irrigation,
c. granular N fertilizer, 2.5 cm irrigation,
d. liquid N fertilizer, 2.5 cm irrigation,
e. granular N fertilizer, 5 cm irrigation, and
f. liquid N fertilizer, 5 cm irrigation.

Evaluation of BMPs: Supplemental irrigation increased both soil water percolation and NO_3-N leaching losses. Application of 2.5 cm of water each time the soil water deficit reached 50% (partial replenishment irrigation) minimized percolation and leaching losses compared to application of 5 cm of water (full replenishment irrigation). Periodic application of liquid N through the irrigation system reduced the average annual NO_3-N leaching loss by about 12 kg/ha at the 5 cm irrigation level, but the method of N management did not affect leaching loss at the 2.5 cm irrigation level.

The corn management system combining partial replenishment irrigation with periodic application of fertilizer N in the irrigation water should sustain high corn yields and help minimize soil water percolation and NO_3-N leaching losses.

B. BMPs for Tillage

Title: Phosphorus losses in runoff as affected by tillage

Authors: Andraski, G.J., D.H. Mueller, and T.C. Daniel

Published: 1985

Source: Soil Science Society of America Journal. 49: 1523-1527.

Study site: Wisconsin, U.S.A.

Study period: 1980 to 1983

Description: Surface runoff, generated by simulated rain, was analyzed for phosphorus concentrations under conventional tillage and three conservation tillage systems: chisel plow, till-plant and no-tillage. Fertilizer was surface applied to the study plots.

Evaluation of BMPs: Conservation tillage reduced total P concentrations and losses by controlling erosion. The no-tillage, chisel plow and till-plant treatments reduced total P losses by an average of 81%, 70% and 59%, respectively, relative to conventional tillage. The no-tillage, chisel plow, and till-plant treatments reduced algae-available phosphorus by an average of 63%, 58% and 27%, respectively, relative to conventional tillage.

The practice of surface banding of fertilizer P at planting eliminated P input to runoff from conservation tilled land.

Title: Long-term effects of tillage and crop rotation on the leaching of nitrate and pesticides to shallow groundwater

Authors: Kanwar, R.S., D.E. Stoltenberg, R. Pfeiffer, D.L. Karlen, T.S. Colvin, and M. Honeyman

Published: 1991

Source: Pages 655-661 *in* Irrigation and drainage. Speciality Conference sponsored by Irrigation and Drainage Division of American Society of Civil Engineers, New York, NY.

Study site: Iowa State University's Northeast Research Centre, Nashua, Iowa, U.S.A.

Study period: 1990

Description: Shallow groundwater and subsurface drain water were monitored for NO_3-N and pesticide leaching under four tillage systems (moldboard plow, chisel plow, ridge tillage and no-tillage) and two crop rotations (continuous corn and corn-soybean).

Evaluation of BMPs: The average monthly NO_3-N concentrations in subsurface drainage water from conventional tillage plots were always greater than 56 mg/L under continuous corn and were greater than concentrations under the other tillage systems. The greater subsurface drain flow from the no-tillage plots under continuous corn resulted in the largest NO_3-N losses (107.2 kg/ha) in comparison with the NO_3-N losses from other three tillage systems. The no-tillage system under continuous corn increased infiltration and decreased NO_3-N concentration in the groundwater, but increased the total volume of NO_3-N and herbicide moving to the groundwater.

Title: Watershed runoff and nitrogen loss from ridge-till and conventional-till corn

Authors: Kramer, L.A., A.T. Hjelmfelt, and E.E. Alberts

Published: 1989

Source: American Society of Agricultural Engineers Paper No. 89-2502, 21 p.

Study site: Southwest Iowa, U.S.A.

Study period: 1974 to 1988

Description: Nitrate-nitrogen and ammonium-nitrogen concentrations in surface runoff and groundwater were measured on three corn-cropped watersheds in deep loess soil. The watersheds were either ridged tilled with a till-planter, ridge-tillage terraced or tilled conventionally. Nitrogen fertilizer was applied at rates recommended for maximum crop yields.

Evaluation of BMPs: NO_3-N losses in surface runoff from the ridge-tillage terraced watershed were greater than losses from the conventional tillage and contour ridge-tillage watersheds each season. Except for the early crop establishment period, NO_3-N losses in surface runoff were greater from the contour ridge-tillage watershed than from the contour conventional tillage watershed.

Average annual NO_3-N loss in groundwater flow from the contour ridge-tillage watershed was nearly three times that from the contour conventionally tilled watershed in each season. The NO_3-N losses from the ridge-tillage watersheds were about 20% of the nitrogen applied as fertilizer.

Groundwater flow amounts and NO_3-N concentrations from the ridge-tillage watersheds were greater than those from the conventional tillage watershed. Consequently, the NO_3-N losses were also greater from the ridge-tillage watersheds. Average annual NO_3-N losses from the ridge-tillage watersheds were nearly three times losses from the conventionally tilled watershed. Total nitrogen loss in groundwater on the conventionally tilled watershed was 7% of the nitrogen applied as fertilizer. On the ridge-tillage watersheds, nitrogen losses were about 20% of the applied amount.

Average annual NO_3-N concentrations in the groundwater were greater than concentrations in surface runoff. During each season, NO_3-N concentrations in the groundwater from the ridge-tillage watersheds were more than twice as high as concentrations from the conventional tillage watershed. Average annual NO_3-N concentrations in groundwater flow were above the 10 ppm water quality standard in all seasons for both the conventional and ridge-tillage watersheds.

Title: The effect of conventional and no-tillage on water quality

Authors: Masse, N., K. Patni, B.S. Clegg, and P.Y. Jui

Published: 1991

Source: Canadian Society of Agricultural Engineers Paper no. 91-110.

Study site: Animal Research Centre Farm of Agriculture Canada, Ontario, Canada

Study period: 1990 to present (study will continue to 1993)

Description: A 14 ha tile drained field was monitored for groundwater and tile water quality from clay loam plots under conventional tillage and no-tillage. The crop was silage corn. Concentrations of nitrate and two commonly used herbicides, metolachlor and atrazine, were analyzed.

Evaluation of BMPs: Leaching of atrazine and its metabolite deethylatrazine to groundwater was significantly higher under no-tillage than under conventional tillage. Atrazine concentrations were generally below the U.S. EPA drinking water standard of 3 μg/L.

Metolachlor was detected in groundwater only in the fall, in approximately one third of the samples. The highest concentration was approximately half the U.S. EPA drinking water standard of 10 mg/L. No significant difference was observed between treatments.

In both treatments, NO_3-N concentrations in groundwater decreased with sampling depth and were generally above the Canadian drinking water standard of 10 mg/L except at a depth of 4.5 m. Concentrations during the early spring of 1991 appeared to be higher in the conventional tillage plots than under no-tillage at 1.2 and 1.8 m depths.

The highest unit area NO_3-N losses in tile drainage water during the fall of 1990 were found in a no-tillage plot.

Title: Soil and nutrient losses in surface runoff from conventional and no-till corn systems

Authors: Pesant, A.R., J.L. Dionne, and J. Genest

Published: 1987

Source: Canadian Journal of Soil Science. 67: 835-843.

Study site: Lennoxville Research Station, Appalachian region, Quebec, Canada

Study period: May to September of 1974 to 1976

Description: Runoff from no-tillage and conventional tillage plots was collected for three consecutive growing seasons on a tile drained sandy loam with a 9% slope. The water samples were analyzed for nutrient losses (NO_3-N, P, K). The plots were cropped with corn and received a preplant broadcast application of 25, 43.7 and 83 kg/ha of N, P and K, respectively, applied as 5-20-20 at 500 kg/ha each year before planting.

Evaluation of BMPs: Sediment and sediment-associated nutrient losses were much less from the no-tillage corn planted into a chemically killed sod than from the conventional tillage system. Crop yields from the two systems were similar. Compared to the conventional system, the no-tillage system reduced soil loss from 16.8 ton/ha to 1.3 ton/ha annually. Rainfall runoff was also reduced two-fold in a wet year and six-fold in a dry year.

The relation of tillage and the transport of soil-bound nutrients is illustrated by P. On average, 84.9% of the losses of available P were by sediment transport. Consequently, by limiting erosion, no-tillage was significantly lower in P losses than conventional tillage. In contrast, only 9.1% and 19.7% of the losses of available NO_3-N and exchangeable K were by sediment transport. The percentage of NO_3-N, P and K losses in soluble form were consistently less from the conventional tillage system because of incorporation of the fertilizer into the tilled soil.

Title: **Effect of tillage system on runoff losses of surface-applied pesticides**

Authors: Sauer, T.J., and T.C. Daniel

Published: 1987

Sources: Soil Science Society of America Journal. 51: 410-415.

Study site: Arlington Experimental Farm near Arlington, Wisconsin, U.S.A.

Study period: Growing seasons of 1983 and 1984

Description: Four tillage systems (conventional, chisel, ridge-plant and no-tillage) in continuous corn were compared with respect to surface runoff losses of atrazine, alachlor and chlorpyrifos.

Evaluation of BMPs: Conservation tillage systems (chisel, ridge-plant and no-tillage) reduced runoff volumes and soil loss. However, pesticide concentrations in runoff water and sediment from these systems were at times greater than for the conventional (moldboard plow) system. Thus, reduced runoff volumes and erosion with conservation tillage systems were offset by higher pesticide concentrations. Consequently, there were no significant differences between tillage treatments with respect to total pesticide loss.

C. BMPs for Feedlots

Title: Beef feedlot runoff treatment by a vegetative filter

Authors: Lagace, R., R. Adam, and M. Vallieres

Published: 1987

Source: Canadian Society of Agricultural Engineers Paper No. 87-104, 15 p.

Study site: A feedlot at Saint-Augustin, near Quebec City, Canada. The feedlot had a 3% slope and an area of 750 m^2, 20% of which was paved.

Study period: September 1985 to May 1986

Description: The feedlot could accommodate 75 head. Runoff was directed to an experimental settling basin and, for experimental purposes, basin effluent was pumped out and directed to a vegetative filter strip area. The vegetative infiltration area was a gently sloped overland flow type. It was on sandy loam soil and was 108 m long and 16 m wide with a 0.75% slope.

Pollution loads and component treatments were evaluated at the exit of the feedlot, the settling basin and the vegetative filter through water samples drawn by automatic water samplers and flows measured by triangular weirs. Groundwater quality was measured by sampling through piezometers at depths of 1.5 and 3 m in and around the filter area and at the edge of the feedlot.

Evaluation of BMPs: The total amount of effluent leaving the facility between September 10, 1985 and May 1, 1986 was only a few cubic metres. The impact of this effluent on the receiving stream was low in terms of both loadings and volume. At times of discharge, the receiving stream had a flow rate far larger than the filter effluent flow (<0.1 L/sec.)

For low rainfalls, no effluent left the vegetative filter, a 100% treatment of the effluent applied to the filter strip. For the study period, the global treatment obtained from the facility for overland runoff was 99.9% for every measured parameter.

The groundwater analyses did not show any significant groundwater contamination after one year of operation.

Vegetative filter strips are effective in controlling runoff around feedlots and associated sediments, phosphorus and nitrate-nitrogen.

Title: Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff

Authors: Young, R.A., T. Huntrods, and W. Anderson

Published: 1980

Source: Journal of Environmental Quality. 9: 483-487.

Study site: Stevens County, in west central Minnesota, U.S.A.

Study period: 1977 to 1978

Description: A rainfall simulator was used to test vegetative strips for their ability to control pollution from feedlot runoff. The filter strips were seeded with orchardgrass, sorghum and sudangrass for one year and the next year the strips were seeded with corn and oats. The feedlot had 310 head of cattle at the time of the study.

Evaluation of BMPs: Cropped buffer strips on a 4% slope reduced runoff and total solids transported from a feedlot by 67% and 79%, respectively. Total N and P were reduced by an average of 84% and 83%, respectively. Ammonium-N and PO_4-P were similarly reduced, but average NO_3-N in the runoff increased because some NO_3-N was gained from the sorghum-sudangrass and the oat buffer strips. During both years, the number of coliform organisms in the runoff water was reduced after runoff passed through the vegetated buffer strips.

2.3 CONCLUSIONS

Best Management Practices include structural (physical and vegetative) controls, cultural practices and management practices. Recommended BMPs are not necessarily universally applicable. A BMP's suitability to a particular area will depend on such factors as farming practices, climate, soil, crop and chemicals used. Factors influencing nitrate, phosphorus and pesticide contamination of surface water include topography, vegetative structures, timing and amount of chemical application, nature of the chemical, cultural practices and soil characteristics. Factors influencing nitrate and pesticide contamination of groundwater include the nature of the chemical, crop needs, timing and rate of applications, subsurface characteristics, depth to groundwater, timing and rate of irrigation and natural rainfall (Canter 1987).

Changes in water quality indicators have been linked to normal agricultural practices such as tillage, continuous cropping, pesticide use and spreading of manure and chemical fertilizers (Phillips et al. 1981). These indicators are used to evaluate the effectiveness of BMPs in reducing agricultural pollution of water. BMPs may not be adopted voluntarily by farmers unless the practices are economical.

Fertilizer, Manure and Pesticide Best Management Practices

It is generally agreed that excessive (beyond crop requirements) applications of phosphorus fertilizer, nitrogen fertilizer, manure and irrigation water will result in increased nonpoint contamination of surface water and groundwater. Soil tests should be done to determine the proper amount of nutrients to apply to the crop (Patni and Culley 1989). Split applications of N-fertilizer may help to minimize nitrogen loss without affecting crop yields (Kanwar et al. 1988). Integrated pest management is recommended to minimize pesticide applications (Coote and MacDonald 1978). As well, farmers and operators should handle chemicals safely (e.g. mix chemicals away from water sources, avoid back-siphoning) and dispose of chemicals and chemical containers properly.

Timing of applications of fertilizers, manure and pesticides is also a critical factor governing nutrient and pesticide contamination of groundwater and surface waters (Gish and Helling 1989; Phillips et al. 1981). Applications immediately before rainfall or irrigation events will result in higher losses of the applied chemicals into receiving groundwater and surface waters.

Tillage Best Management Practices

Many studies have assessed the impacts of no-tillage on nutrient losses in runoff but not all arrive at the same conclusions. Studies show that most of the phosphorus in agricultural runoff is normally attached to sediment. Because no-tillage reduces soil loss, it shows promise for reducing total P in runoff and, presumably, total P inputs to surface waters (Coote and MacDonald 1978; Pesant et al. 1987; Beke et al. 1989). However, other studies indicate no-tillage may increase the amount of soluble NO_3-N and P in runoff (Mueller et al. 1984; McDowell and McGregor 1980) because the fertilizer is not incorporated into the soil (Pesant et al. 1987).

Best Management Practices for Feedlots

Runoff from cattle feedlots is widely recognized as a potential pollutant of receiving watercourses (Lagace et al. 1987). The best way to control feedlot runoff is to install a runoff catchment basin (Young et al. 1980). However, catchment basins have several disadvantages including cost, odour and maintenance requirements.

Vegetative filters strips have been shown to be an effective alternative to catchment basins. These strips reduce runoff and hence reduce the concentrations of nitrate, phosphorus, sediments and microorganisms entering surface waters (Dillaha et al. 1988; Magette et al. 1989; Lagace et al. 1987; Young et al. 1980). There is still uncertainty about the impact of vegetative strips on groundwater quality, and research is continuing on this aspect.

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3.0 WATER QUALITY MODELS

3.1 INTRODUCTION

Best Management Practices (BMPs) must be tailored to the local farming practices, climate, soil, crop and contaminant but field evaluations of practices are often expensive and time-consuming. Water quality models can be a cost-effective alternative to field evaluations, once the models have been tested and validated under local conditions. With climate, crop, soil and topographic information, these models can help assess the impact of agricultural activities, identify target areas for BMPs implementation and evaluate BMPs under various environmental scenarios in seconds or minutes using a personal computer. A wide range of plot, field and watershed scale models have been developed and tested.

In the following section, a software tool to help users select the most appropriate water quality model is described, and then various water quality models are summarized in terms of input requirements, output, advantages and limitations.

3.2 WATER QUALITY MODELS LITERATURE SUMMARY

3.2.1 Water Quality Model Selection Advisor

Model: MOD-C-LECT

Source:
Texas A & M University System
Texas Agricultural Experimental Station
Blackland Research Center
808 East Blackland Road
Temple, Texas, U.S.A. 76502

Contact:
Ray H. Griggs
Phone: (817) 770 - 6600
Fax: (817) 770 - 6561

Description: This model selecting tool helps the user search through the following areas:
1. Hardware/software requirements
2. Resolution/scale
3. Hydrology/routing
4. Erosion
5. Impoundments and other structures
6. Crop growth
7. Management
8. Nutrients, pesticides and other pollutants
9. Economics
10. Input/output

The tool uses artificial intelligence and object-orientated programming to direct the user toward the model(s) that meet(s) all the user's selection criteria. Hypertext files help describe the models, define variables and define terms associated with water quality.

Comments: This tool is in the final stages of development (Griggs 1990). Griggs can be contacted directly to assist in a model search and evaluation.

3.2.2 Surface Runoff Models

Model: AGNPS (AGricultural NonPoint Source Pollution model)

Agency: USDA-ARS
N. Central Soil Conservation Res. Lab.
North Iowa Avenue
Morris, Minnesota, U.S.A. 56267

Contact: Dr. Robert Young
Phone: (612) 589 - 3411
Fax: (612) 589 - 3787

Event(s) modeled: Sediment and nutrient transport

Practice(s) evaluated: Pre and post adoption of soil conservation, feedlot Best Management Practices

Description: AGNPS is a grid-based model designed to identify "hot spots" in a watershed and estimate improvements with adoption of Best Management Practices. It estimates runoff quality from moderately sized agricultural watersheds (20,000 ha or about 50,000 ac) after a precipitation event. The components of the model include hydrology, erosion, and sediment and chemical transport. In addition, the model considers point sources of sediment from gullies and inputs of water, sediment, nutrients and COD from feedlots, springs and other point sources (Young et al. 1989).

Time and space scale: Storm event; watershed scale runoff

User requirements: IBM or compatible personal computer, math coprocessor advised.

Input requirements:

1. Weather data
   - precipitation
   - energy-intensity value of precipitation

2. Parameters for each cell
   - Soil Conservation Service (SCS) curve number
   - land slope
   - slope shape factor
   - field slope length
   - channel slope
   - channel sideslope
   - Manning's roughness coefficient
   - soil erodibility factor
   - cropping factor

- practice factor
- surface condition constant
- aspect
- soil texture
- fertilization level (N,P)
- availability factor of fertilizer
- point source indicator
- gully source indicator
- chemical oxygen demand
- impoundment factor (type of reservoir)
- channel indicator (type and size of channel)

Output:

1. Hydrology: runoff volume, peak runoff rate, fraction of runoff generated within the cell

2. Sediment: sediment yield, sediment concentration, particle size distribution, upland erosion, amount of deposition, sediment generated within the cell, enrichment ratios and delivery ratios by particle size

3. Chemical: sediment-associated mass, and concentration and mass of soluble material

4. Phosphorus: sediment-associated mass, and concentration and mass of soluble material

5. Chemical oxygen demand (COD): concentration and mass

Comments: AGNPS should be used cautiously when designing conservation practices for large storm events because many small storms can have a significant effect on antecedent soil moisture (Binger et al. 1992). Statistical evaluation of the grid size comparison demonstrated that the smallest grid size available should be used (Feezor et al. 1989). All the larger grid size parameter ratios were significantly different from 1 at the 90% confidence level.

Model: **EPIC (Erosion Productivity Impact Calculator)**

Agency:
USDA-ARS
Grassland, Soil and Water Research Laboratory
808 East Blackland Road
Temple, Texas, U.S.A. 76504

Contact:
Dr. J. (Jimmy) R. Williams
Phone: (817) 770 - 6508
Fax: (817) 770 - 6561

Event(s) modeled: Erosion, crop growth

Practice(s) evaluated: Soil conservation

Description: EPIC consists of eight components: hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage and economics. The hydrology component simulates surface runoff volume and peak discharge. Water erosion is simulated with a modification of the Universal Soil Loss Equation (USLE). Two plant nutrients are considered: nitrogen and phosphorus. A general plant growth model simulates above-ground biomass, yield and roots for both annual and perennial crops. Soil temperature is simulated to serve the nutrient cycling and root growth components of EPIC. The EPIC tillage model simulates row height, surface roughness, change in bulk density, transition from standing to flat residue and mixing of soil layers, nutrients and plant residue for any tillage operation. EPIC's economics component uses a crop budget to calculate crop production costs.

Time and space scale: Annual; plot, field or small watershed

User requirements: IBM or compatible personal computer

Input requirements:

1. Weather data
    - TP-40 10 year rainfall record
    - mean monthly minimum and maximum temperature
    - daily precipitation
    - monthly, daily solar radiation
    - monthly mean relative humidity
    - wind speed

2. Soil data
    - initial soil water content-fraction of field capacity
    - minimum and maximum depth to water table
    - initial depth to water table

3. Soil data by horizon
    - depth from the surface to the bottom of the soil layer
    - bulk density
    - wilting point
    - field capacity
    - soil composition
    - soil pH

4. Management data
    - irrigation, fertilizer and tillage schedule
    - water stress factor to trigger automatic irrigation
    - irrigation runoff ratio
    - maximum and minimum single application volume under automatic irrigation
    - N stress factor to trigger automatic fertilizer
    - fraction of maximum N fertilizer applied at planting
    - maximum annual N fertilizer application for a crop
    - fraction of furrow dike volume available for storage

5. Crop parameter data
    - 36 crop parameters are input for each crop simulated in the model. Factors that affect water and N supply are the most important.

6. Equipment/tillage operation parameter data

- the economics, roughness and ridge heights left by tillage equipment are specified in 10 parameters.

Output: EPIC simulates

1. hydrologic condition
2. sediment erosion
3. soil nutrient properties
4. soil temperature on the surface and in the soil layer
5. the effect of tillage on the soil
6. plant growth stage
7. daily weather, if measured
8. seasonal crop yield

Comments: EPIC does well in predicting the effect of tillage under soil and weather conditions similar to those in Iowa locations and in Wood County, Ohio, but it does not handle the effect of tillage for the soil/weather conditions in Wayne County, Ohio (Catus et al. 1989). The simulation's predicted variability of percent difference and crop rotation yield difference is lower than the measured variability in all locations.

The model does not predict the effect of crop rotation very consistently (Catus et al. 1989). The predictions were usually opposite to the measured results or not as significant as the measured results. The simulation's variability is lower than the measured variability in all studied locations except for one, Wood County, Ohio.

Results at Bushland, Texas indicated that EPIC is best suited to making long-term management decisions (Williams et al. 1989).

Model: GAMESP (Guelph model for evaluating the effects of Agricultural Management Systems on Erosion, Sedimentation and Phosphorus yields)

Agency: School of Engineering
University of Guelph
Guelph, Ontario, Canada, N1G 2W1

Contact Dr. Ramesh P. Rudra
Phone: (519) 824 - 4120, Ext. 2110
Fax: (519) 836 - 0227

Event(s) modeled: Erosion

Practice(s) evaluated: Soil conservation

Description: GAMESP (Rousseau et al. 1988) is the result of the addition of a phosphorus component to GAMES. The GAMESP model consists of two major components: the potential soil loss/sedimentation component, and the phosphorus component. The potential soil loss/sedimentation component estimates the seasonal potential soil loss for each land cell (using a seasonal application of the USLE) and the subsequent seasonal amount of sediment delivered to the adjacent downstream land cell and to the downstream stream cell. The phosphorus component estimates the average total phosphorus concentration of the surface soil for each land cell on a seasonal basis.

The concept of GAMESP involves the discretization of a watershed into field-sized elements with homogenous characteristics of land use, soil type and class of slope. The discretization process allows for the modelling of basins with irregular shaped elements as opposed to the grid cell construction of many watershed models.

GAMESP delineates soil loss and sediment yield source areas and illustrates the relative impact of the implementation of certain soil conservation strategies.

Time and space scale: Seasonal/annual; small watershed

User requirements: A microcomputer equipped with word processor or spreadsheet capable of generating ASCII text files

Input requirements:

1. Maps with a composite overlay of
- land use
- soil
- topography
- drainage network on each cell

2. Soil loss/sedimentation parameters
- seasonal rainfall
- runoff factor
- seasonal soil erodibility factor
- seasonal cover and management factor
- support practice factor
- seasonal topographic factor
- seasonal Manning roughness coefficient
- seasonal hydrologic coefficient

Output:

1. Potential soil loss, sediment and phosphorus yields rates

2. Areas exhibiting potential soil loss, sediment and phosphorus yield

3. For each of these areas, estimates of potential soil loss, sediment and phosphorus yields

Limitations: GAMESP is capable of modelling small agricultural watersheds only and is focused on the management of sediment and particulate phosphorous.

Advantages: GAMESP is easy to use and cost effective, making use of limited amounts of readily available input data and easily quantifiable physical and hydrological characteristics of the watershed.

Comments: GAMESP is a useful model for the preliminary delineation and mapping of source areas of sediment and phosphorus delivery to surface waters of small agricultural watersheds (Rousseau et al. 1988). With modelling of soil management practices and soil conservation strategies, GAMES provides a useful tool to assess the relative impact of soil conservation systems on soil erosion and sediment delivery to streams (Cook et al. 1985).

Model: SWRRB-WQ (Simulator for Water Resources in Rural Basins - Water Quality)

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Grassland, Soil and Water Research Laboratory
808 East Blackland Road
Temple, Texas, U.S.A. 76502

Contact:
Dr. Jeffery Arnold
Phone: (817) 770 - 6502
Fax: (817) 770 - 6561

Event(s) modeled: Runoff, sediment yield

Practice(s) evaluated: Water management

Description: The SWRRB model was developed by modifying the CREAMS daily rainfall hydrology model for application to large, complex, rural basins. The SWRRB model includes three major components: hydrology, weather and sedimentation. Processes considered include surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation and crop growth. SWRRB operates on a daily time step with monthly outputs.

Time and space scale: Monthly; small watershed

User requirements: IBM PC-compatible computer with at least 256K RAM. The program is written in FORTRAN.

Input requirements:

1. Weather data
- 10 years of precipitation data
- daily maximum and minimum temperatures
- monthly solar radiation data
- daily rainfall data

2. Soil data
- type
- sediment size distribution
- maximum rooting depth soil layer parameters
- depth of layers
- bulk density
- available water capacity
- saturated conductivity
- clay content

3. Crop parameters
- planting date
- harvest date

- tillage operation
- maximum leaf area index
- initial residue cover

4. Irrigation parameters
- water stress
- irrigation runoff ratio

5. Site parameters (basin data)
- area
- albedo
- main channel length in each sub-basin
- average channel slope in each sub-basin
- average main channel width
- effective hydraulic conductivity of channel alluvium
- average slope length for each sub-basin
- average slope steepness for each sub-basin

Output:

1. Surface runoff
2. Subsurface flow
3. Water yield
4. Percolation
5. Transmission losses
6. Evapotranspiration
7. Sediment yield

Comments:

SWRRB has been tested on 11 large watershed from eight ARS locations throughout the United States (Arnold and Williams 1987). The results show SWRRB can realistically simulate water and sediment yields under a wide range of soils, climate, land use, topography and management conditions. Also, the model's usefulness in evaluating the effects of flood-control structures was demonstrated at Chichkasha, Oklahoma (Williams et al. 1985). SWRRB should provide a versatile and convenient tool for use in planning and designing water resources projects (Arnold and Williams 1987).

Model: WEPP (Water Erosion Prediction Project)

Agency:

USDA - ARS
Purdue University
West Lafayette, Indiana, U.S.A. 47907

Contact:

Dr. John M. Laflen
Phone: (317) 494 - 8673
Fax: (317) 494 - 5948

Event(s) modeled: Runoff and soil loss

Practice(s) evaluated: Soil conservation

Description: WEPP is a water erosion simulation model with a daily time step. The processes involved include erosion, hydrology, plant growth and residue, water use, hydraulics and soil physics.

WEPP comes in three versions: profile, watershed and grid. The profile version is a direct replacement of USLE, with the added ability to estimate sediment deposition on a slope. The watershed version applies to a "field-size" watershed. The grid version applies to an area whose boundaries do not coincide with watershed boundaries.

Time and space scale: Continuous; field (up to 260 ha (640 ac))

User requirements: 80386 or better microprocessor with math coprocessor and a UNIX operating system

Input requirements:

1. Site parameters
- number of overland flow elements
- number slope elements
- relative length and gradient of slope elements
- field aspect, degrees from north
- field dimensions (width and length)

2. Soil data
- type
- texture
- number layers
- albedo
- initial saturation
- baseline interrill detachment
- baseline rill detachment
- baseline critical shear
- layer characteristics (accumulative thickness, initial bulk density, initial saturated hydraulic conductivity, field capacity, wilting point, percent sand, percent clay, percent organic matter, cation exchange capacity, percent rock fragments)

3. Daily climate data
- precipitation (amount, duration, normalized time to peak intensity and normalized peak intensity)
- maximum and minimum temperature
- wind velocity and direction
- solar radiation

4. Crop type
- leaf area index
- root depth
- residue cover

5. Topography

6. Management practices

Output:

1. Sheet and rill erosion and deposition by overland flow along selected landscape profiles or over an entire field
2. Concentrated flow erosion along selected channels over the entire channel network within a field
3. Sediment yield and sediment characteristics from selected watersheds within the field area at all outlet points from the fields

Limitations: WEPP is limited to sheet and rill erosion and to erosion occurring in channels where detachment is due to hydraulic shear. This excludes erosion in classical gullies or continuously flowing streams. A gully component for WEPP is under development. The upper limit of the field-size area is determined by the erosion and hydrologic processes that may occur. (Kramer et al. 1991; Laflen et al. 1991).

Advantages: Unlike the USLE, the profile WEPP version has the ability to estimate sediment deposition on a slope.

3.2.3 Water Table Management Models

Model: DRAINMOD, a water management simulation model for artificially drained soils, Version 4.0

Agency:
North Carolina State University
Biological and Agricultural Engineering
208 D.S. Weaver Labs,
Box 7625,
Raleigh, North Carolina, U.S.A. 27695-7625

Contact:
Dr. Wayne Skaggs/Dr. Robert O. Evans
Phone: (919) 515 - 6788
Fax: (919) 515 - 6772

Event(s) modeled: Water table depth

Practice(s) evaluated: Design of subsurface drainage, subirrigation and controlled drainage systems

Description: DRAINMOD is used to simulate the performance of subsurface drainage, subirrigation and controlled drainage systems. The simulation is based on a water balance in the soil profile and uses climatological, soils, crop, and drainage system data as inputs. The processes involved include infiltration, surface and subsurface drainage, and evapotranspiration.

Version 4.0 has the YIELD version built in, allowing prediction of planting delays and soil water stress on crop yield to be done simultaneously.

Time and space scale: Continuous; plot to field

Model: **SWACROP, a water table management model**

Agency: The Winand Staring Centre for Integrated Land, Soil, & Water Research (SC),
P.O. Box 125,
6700 AA Wageningen, The Netherlands

Contacts: R.A. Feddes (Winand Staring Centre)

Dr. Ramesh P. Rudra (University of Guelph, Guelph, Ontario)
Phone: (519) 824 - 4120, Ext. 2110
Fax: (519) 836 - 0227

Event(s) modeled: Water table depth

Practice(s) evaluated: Design of subsurface drainage, subirrigation and controlled drainage systems

Description: SWACROP is the most recent version of the soil water balance model, SWATRE (Soil Water Actual Transpiration Rate Extended) developed by Belmans et al. (1983). It includes SWATRE and a crop production model, CROPR. The CROPR simulation model was developed by Feddes et al. (1978). CROPR was incorporated into SWATRE by Feddes et al. in 1984.

Time and space scale: Continuous simulation, field scale.

User requirements: IBM compatible PC with a math coprocessor (8087/80287) after compilation with the Microsoft FORTRAN 77 compiler version 3.31 or higher

Input requirements:

1. Climatological data
   - daily precipitation
   - daily pan evaporation

2. Soil data by horizon
   - horizon depth
   - soil composition
   - bulk density
   - percent moisture retention

3. Crop parameters
   - rooting depth as a function of time
   - soil cover function
   - leaf area function
   - soil water content
   - unsaturated hydraulic conductivity as a function of water tension or soil water content
   - saturated hydraulic conductivity

4. Drainage system parameters
   - drain spacing
   - drain depth
   - drain diameter

- effective drain radius
- radial resistance
- transmissivity
- drainage coefficient
- weir levels
- initial ground water level
- depth drain to impermeable layer

Output: Water balance of the soil profile

- daily water content and pressure head
- infiltration, percolation, runoff, irrigation, canopy, interception, potential and actual transpiration, soil evaporation, and root water extraction in each level of the soil profile

Limitations: SWACROP is incapable of simulating a fluctuating water table that rises to the soil surface.

Comments: SWACROP seems to have the potential to be used for designing or evaluating subsurface drainage and subirrigation systems in southern Ontario (Aheer et al. 1992) and SWACROP can be used to evaluate or design subsurface drainage systems in Atlantic Canada (Mathur et al. 1992).

3.2.4 Groundwater Models

Model: ADAPT (Agricultural Drainage And Pesticide Transport)

Agency: Ohio State University
Agricultural Engineering Department
Ives Hall
Columbus, Ohio, U.S.A. 43210

Contact: Dr. Andrew D. Ward
Phone: (614) 422 - 6132

Event modeled: Water quality as affected by water table management

Practice evaluated: Water table management

Description: ADAPT model has three components: hydrology, erosion and pesticide transport. It is an extension of the GLEAMS daily simulation model with a capability to account for subsurface drainage and subirrigation from DRAINMOD. The hydrology submodel includes snowmelt, runoff, macropore flow, evapotranspiration, infiltration, subsurface drainage, subirrigation and deep seepage. Parameter values from the hydrology and erosion components are carried over to the pesticide component of the ADAPT model.

Time and space scale: Continuous; field

User requirements: IBM or compatible personal computer

Input requirements:

1. Weather data
   - daily rainfall
   - air temperature
   - solar radiation
   - relative humidity
   - wind speed

2. Soil data by horizon
   - layer thickness
   - porosity
   - organic matter content
   - wilting point
   - hydraulic conductivity
   - impermeable layer conductivity

3. Crop data
   - crop type
   - effective rooting depth
   - leaf area index as a function of growth stage

4. Subirrigation/drainage system data
   - drain depth
   - drain spacing
   - drain diameter
   - outlet weir height
   - depth to impermeable layer
   - drainage coefficient

5. Pesticide parameters
   - application date
   - amount applied
   - method of application
   - pesticide water solubility
   - soil half-life
   - partitioning coefficient

Output:

1. Monthly sums of surface runoff, subsurface drainage, combined surface runoff and tile drainage volumes, monthly rainfall, evapotranspiration, deep seepage and subirrigation volumes

2. Pesticide concentration and mass in surface runoff, sediment, tile drainage and deep seepage

3. Pesticide concentrations in the soil layers and masses degraded and taken up by the plant

Comments:

The ADAPT model predicts pesticide transport satisfactorily, and can be used for agricultural water quality management systems (Chung et al. 1991; Kalita et al. 1992). With little or no calibration, the ADAPT model provides reasonable estimates of pesticide concentration in perched water tables and pesticide losses due to surface runoff, subsurface drainage, plant uptake and decomposition for three water table management field facilities in northern Ohio (Chung et al. 1992).

Model: **GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)**

Agency:

University of Georgia
Coastal Plain Experiment Station
Department of Biological and Agricultural Engineering
P.O. Box 748
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Contact:

Dr. Walter G. Knisel
Phone: (912) 386 - 3959
Fax: (912) 386 - 3958

Event(s) modeled: Chemical losses in surface runoff, sediment and percolation below the root zone

Practice(s) evaluated: Pesticide and crop management

Description: GLEAMS was developed from the CREAMS model (Knisel 1980) to evaluate chemical losses in surface runoff and sediment from field-sized areas (Leonard et al. 1987). GLEAMS includes pesticide leaching below the root zone and nitrate leaching (version 2.0 with nutrient component to be published in July 1, 1993). GLEAMS was designed to provide relative comparisons among different management-climate-soil-pesticide conditions.

GLEAMS has three major components: hydrology, erosion and pesticides. The hydrology component uses daily precipitation inputs along with soil and crop characteristics to compute soil-water-balance in the root zone. The erosion component uses the modified USLE (Wischmeier and Smith 1978) for storm-by-storm simulation of rill and interrill erosion in overland flow areas. The pesticide component estimates pesticide concentrations and mass transported in runoff, attached to sediment, and in water moving within and through the root zone. GLEAMS is a continuous, daily simulation model.

Time and space scale: Continuous; field

User requirements: IBM-compatible computer

Input requirements:

1. Weather data
- daily precipitation
- mean daily maximum and minimum temperature
- mean monthly solar radiation

2. Soil data by horizon
- porosity
- horizon depths
- bulk density
- moisture content at field capacity
- moisture content at wilting point
- initial moisture content
- percent organic matter

3. Hydrological parameters
    - watershed area
    - saturated conductivity
    - evaporation coefficient
    - SCS curve number
    - channel slope
    - watershed length/width ratio
    - peak flow rate coefficient
    - peak flow rate exponent

4. Crop parameters
    - leaf area index
    - winter cover factor
    - rooting depth

5. Pesticide properties
    - solubility
    - partition coefficient
    - foliar half-life
    - soil half-life
    - coefficient of plant uptake

Output:

1. Monthly and annual water budget data, including rainfall, net rainfall, surface runoff (storm flow), evapotranspiration, percolation and average soil water content

2. Pesticide mass loss and percent of application in stormflow, adsorbed to sediment, and in the percolate below the root zone

3. Concentration of pesticide in the storm flow and leachate

4. Sediment yield

Limitations:

GLEAMS does not simulate water and chemical movement below the root zone.

The number of layers the soil profile may have is a minimum of three and a maximum of 12.

Advantages:

Up to 10 chemicals can be simultaneously simulated.

The first layer is defined to be 1 cm in depth. This increases the sensitivity of erosion and runoff to chemical concentrations near the soil surface.

The model does not require calibration for use, is easily understood, and requires few and readily available parameters (Crawford et al. 1991).

Model: LEACHM (Leaching Estimation And CHemistry Model)

Agency: Department of Agronomy
Cornell University
Ithaca, New York, U.S.A. 14853-5701

Contact: J.L Hutson and R.J. Wagenet
Fax: (607) 255 - 4080

Event(s) modelled: Leaching

Practice(s) evaluated: Fertilizer and pesticide management

Description: LEACHM provides very detailed modelling (10 minutes of computing time per day) of the movement of nutrients, pesticides and inorganic ions. It models leaching processes through the root zone and into shallow water tables. No surface runoff processes are modelled.

Time and space scale: Continuous; field scale

User requirements: Microcomputer

Model: RUSTIC (Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations); formerly PRZM (Pesticide Root Zone Model)

Agency: U.S. Environmental Protection Agency
Athens Environmental Research Laboratory
College Station Road
Athens, Georgia, U.S.A. 30613

Contact: Dr. Robert F. Carsel
Phone: (404) 546 - 3565

Event(s) modeled: Pesticide movement within and below the root zone

Practice(s) evaluated: Pesticide management

Description: RUSTIC is a continuous simulation field scale model designed to simulate chemical (pesticide) movement within the entire vadose zone (soil surface to groundwater). The model has two major components: the hydrology component for simulating runoff and erosion; and the chemical transport component. The hydrology component uses the SCS curve number for predicting runoff. The erosion component uses a modified version of the USLE.

The chemical component used in the RUSTIC model accounts for pesticide uptake by plants, surface runoff loss, foliar losses, erosion losses, degradation, advection, dispersion and retardation.

RUSTIC will simulate multiple applications of a single pesticide each year for many years of continuous climatic record.

Time and space scale:	Continuous; field
User requirements:	IBM-compatible computer
Input requirements:	1. Weather data - daily rainfall volume - daily mean temperature or daily pan evaporation - mean monthly solar radiation 2. Soil data by horizon - horizon depths - porosity - percent organic carbon - partition coefficient - bulk density - moisture content at field capacity - moisture content at wilting point - initial moisture content 3. Hydrologic parameters - soil erodibility - USLE topographic factors (K, LS, P) - area of site - duration of runoff hydrograph - runoff curve number 4. Crop parameters - maximum rooting depth - maximum canopy coverage - interception storage 5. Pesticide data - water solubility - sorption coefficient - foliar half-life - soil half-life - foliar wash-off rate - application type, date, amount, etc.
Output:	1. Runoff 2. Percolation 3. Evapotranspiration 4. Mass flux of chemicals through the root zone (pesticide loss by percolation)
Limitations:	The first layer is set at 2 cm to decrease the sensitivity of surface runoff. RUSTIC simulates only a single solute (no metabolites).
Advantages:	RUSTIC can simulate agricultural chemical transport below the root zone.

Comments:	RUSTIC's 2-cm thick surface interactive zone can result in overprediction of erosion and surface pesticide losses, as shown in a study by Lehman et al. (1990) in which pesticides were applied at a 1 cm depth. RUSTIC can overpredict percolation because it does not limit the percolation rate based on saturated hydraulic conductivity. Also, the model may underpredict plant uptake because the soil moisture does not go above field capacity (Smith et al. 1989; Smith et al. 1991).

3.3 CONCLUSIONS

Many water quality models are available to the public at little or no cost. These models are designed to evaluate soil, nutrient and pesticide transport and fate, as affected by agricultural practices. Water quality models can be used to compare management options regarding chemical, nutrient and sediment losses. No model has been shown to give very accurate predictions in terms of absolute values over a wide range of conditions (Leonard 1986).

Water quality models are usually evaluated by observations on a plot or field scale because of time constraints; on a watershed scale, water quality response to changes in agricultural practices takes many years. However, several models are being evaluated on a watershed scale. The RCWP projects use AGNPS, CREAMS, ANSWERS and USLE to model the effectiveness of BMPs. These models are not yet verified by observations from watersheds with water quality problems because RCWP projects are just reaching completion (Maas et al. 1988).

Models are updated, revised and integrated as understanding grows about the nature and method of sediment, nutrient and chemical transport. Given the improving representation of critical processes and improving data bases, nonpoint source pollution models show considerable promise in becoming valuable planning and management tools (Dickinson 1987).

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4.0 PLANNING PRINCIPLES FOR NONPOINT POLLUTION CONTROL PROJECTS

4.1 INTRODUCTION

Control of water pollution from agricultural nonpoint sources requires detailed planning for effective project development, implementation and evaluation. This chapter summarizes some key principles for project planning based on two successful examples: the Belgrave Creek project in Ontario (Puddister 1985); and the Rural Clean Water Program in the United States (Coffey et al. 1992; Gale et al. 1992; Maas et al. 1988; Smolen and Smith 1989).

4.2 PLANNING PRINCIPLES SUMMARY

Project: Belgrave Creek, Ontario, Canada

Problem: Sediment from nonpoint source

Agencies: Ontario Ministry of Natural Resources initiated the assistance program; Ontario Ministry of the Environment established an ongoing monthly water quality sampling station; and Wingham District of the Ontario Ministry of Natural Resources provided the local contact.

Key principles:

1. Detailed background inventory
2. Site prioritization
3. Landowner cooperation
4. Interagency cooperation
5. Adequate funding
6. Clearly defined program administration
7. Effective program evaluation
8. Communication of results
9. Post-project monitoring

Project: Rural Clean Water Program (RCWP), United States

Problem: Watersheds with one or more of the following pollutants: pesticides, phosphorus, nitrate and microorganisms. Pollutant sources include swine waste, cropland nutrients, irrigation tract erosion, cropland erosion and dairy waste.

Agencies: U.S. Agricultural Stabilization and Conservation Service, in consultation with U.S. Environmental Protection Agency

Key principles:

1. Pre-implementation monitoring
   - a detailed, documented monitoring of the water quality, minimum two years to establish baseline data

2. Project criteria
- water quality problem must be well defined and documented
- agricultural activities must be the primary pollution source
- critical pollutant source areas must be well defined and the area must encompass the major pollutant sources

3. Participation
- information and education programs must be in place to gain participation of the farming community and general public
- a cost-share program is optional to gain farmers' participation

4. Funding
- adequate funding must be committed for the entire project period

5. Time frame
- anticipated time frame for obtaining and observing water quality improvement for watershed level nonpoint source pollution control efforts:

Water resource type	**Project period** (years)
Irrigation canal	3-8
Stream	5-13
Estuary	5-12
Lake	6-14
Groundwater aquifer	unknown

6. Cooperation among participants
- interagency cooperation must be present
- participating agencies, institutions, landowners and operators should have clearly defined roles and responsibilities

7. Properly defined objectives and goals
- objectives should relate to the designated or expected use of the water resource
- objectives should have measurable end points or accomplishments toward which the project participants are striving
- goals need to be realistic, specific and measurable

8. Implementation
- critical pollution source areas should be priorities for BMP implementation
- one-to-one contact between project personnel and farmers needs to occur to gain participation
- intensive water quality monitoring program should be undertaken
- technical support and feedback to farmers should occur to maintain participation

9. Evaluation
- continued monitoring is needed to document water quality status

Comments: Successful projects had most of the above elements. Water quality improvements could not be documented on some projects for several reasons including:
- a lack of participation from the farming community due to economic reasons and/or dislike of government programs and employees
- a lack of funding

- agricultural activities were not the primary pollution source
- monitoring designs were inadequate to document water quality improvements

4.3 CONCLUSIONS

The Rural Clean Water Program and the Belgrave Creek project have shown that water pollution from agricultural nonpoint sources can be controlled at a reasonable cost with existing technology and approaches. The key principles contributing to the success of these two North American examples have been summarized in this chapter. These principles can provide a useful framework for planning the development, implementation and evaluation of future projects.

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6.0 GLOSSARY AND ABBREVIATIONS

Most of the following definitions are from Gale et al. (1992).

Animal waste management system - A Best Management Practice designed to minimize pollution originating from livestock or poultry operations by providing facilities for the storage and handling of animal wastes, primarily manure.

Agriculture Canada - Federal department of agriculture with responsibilities in primary agricultural research, soil and water conservation technical and program support.

Alberta Agriculture, Food and Rural Development - formerly Alberta Agriculture. Provincial department of agriculture with responsibility of advising farmers in Alberta on best practices and management.

Alberta Environmental Protection - Provincial department with the responsibility of protecting air, water and land quality in Alberta.

Anions - Negatively charged ions. In soils, anions like NO_3^-, Cl^-, OH^- and SO_4^{--} are usually in the soil water.

ARS (Agricultural Research Service) - Agency of the United States Department of Agriculture.

BMPs (Best Management Practices) - Practices or structures designed to reduce the quantities of pollutants such as sediments, nitrogen, phosphorus, pesticides and animal wastes that are washed by rain and snowmelt from farms into groundwater or nearby surface waters, such as lakes, creeks, streams or sloughs. Agricultural BMPs can include simple changes like fencing cattle out of streams (to reduce stream bank erosion and manure in the stream), grassing gullies and conservation tillage (to reduce sediment in runoff water). BMPs can also involve building structures, such as feedlot runoff holding ponds, to prevent runoff contaminated with manure from reaching nearby watercourses.

BOD (biochemical oxygen demand) - BOD measures the strength of wastewater. A high BOD indicates that there is plenty of organic matter and nitrogen for microorganisms to consume. Decomposition involves oxygen consumption, and high consumption of oxygen in water by microorganisms deprives higher life forms (e.g. fish, aquatic plants) of dissolved oxygen.

Cations - Positively charged ions. In soils, cations like H^+, K^+, Na^+, Mg^{++} and Ca^{++} are usually adsorbed onto clay particles and organic matter.

Chemigation - Application of herbicides and insecticides on irrigated crops through a sprinkler irrigation system. Because the agricultural chemicals are injected directly into the field's water supply line, a properly installed system must include a backsiphon preventer valve. Otherwise, shutdown of the irrigation system may cause the chemicals to be drawn back into the water supply, either into the groundwater if the water is from an irrigation well or into the surface water if the water is from an irrigation canal.

COD (chemical oxygen demand) - COD is a chemical test that measures part of the oxygen microorganisms would consume in decomposing organic matter.

Coliform bacteria - Bacteria routinely found in untreated surface water. Excessive levels of coliform bacteria in drinking water are an indicator of contamination. Faecal coliform bacteria are present in water that has had contact with animal or human faeces. Drinking water should have no faecal coliform bacteria. Since bacteria are filtered out as water percolates to the groundwater, the presence of coliform bacteria in well water is an indicator that the well has been poorly constructed allowing surface runoff to enter it.

Conservation tillage - A tillage practice or system of practices that leaves plant residues on the soil surface for moisture conservation and erosion control. Minimum tillage and no-tillage are variations on this concept, reflecting the amount of tillage that may or may not occur before seeding operations.

Critical area - An area or source of nonpoint source pollutants identified in the project area as having the most significant impact on receiving waters. Also called a "hot spot".

dS/m (deciSiemens/metre) - metric measure of electrical conductivity (a test for salinity in soil and water).

Electrical conductivity (EC) - A test for the salinity of a soil. A saturated paste is made of the soil and then the liquid is drawn off. The liquid's capacity to carry an electrical current is measured. A measurement greater than 4 deciSiemens/metre (dS/m) is an indicator of a saline soil. At this level, there are enough soluble salts to interfere with the growth of most plants.

EPA (Environmental Protection Agency) - Federal agency of the United States.

Erosion - Wearing away of rock and soil by the gradual detachment of soil or rock fragments by water, wind, ice and other mechanical or chemical forces.

Fertilizer management - A Best Management Practice designed to minimize the contamination of surface and groundwater by limiting the amount of nutrients (usually nitrogen) applied to the soil to no more than the crop is expected to use. This may involve changing fertilizer application techniques, placement, rate and timing. It may involve a series of applications through the growing season to match the fertilizer supply more closely to crop needs.

Groundwater - The water within the saturated zones of the earth's mantle. Groundwater rarely occupies open cavities of "underground lakes or rivers." Aquifers (zones of groundwater) often hold water in small pores between sand particles (sandstone) or, less commonly, in fractures in the rock (fractured shales).

Integrated pest management - A judicious use of both natural predators of pests and agricultural chemicals to control agricultural pests.

K - Potassium, an element essential to plant growth.

Loading - The influx of pollutants to a water body.

Manning's Roughness Coefficient - A coefficient representing the surface roughness of a channel or pipe carrying water. Rough surfaces cause more friction and turbulence to flowing water, reducing its velocity. In agricultural situations, reducing water velocity reduces its erosive power. Since grass cover in a channel is rougher than bare earth, grassed waterways reduce water velocities and erosion much better than bare earth ditches.

Mg/ha - Megagrams per hectare.

mg/L - Milligrams per litre. The equivalent of parts per billion (ppb). Maximum allowable concentrations (MAC) of contaminants are reported in mg/L in Health and Welfare Canada's *Guidelines for Canadian Drinking Water Quality*.

mL - Millilitre. The volume of liquid equivalent to 0.035 fluid ounces or 1 cubic centimetre.

µg/L - Micrograms per litre. One microgram is equal to 0.001 milligrams.

N - Nitrogen. An element occurring in manure and chemical fertilizer that is essential to the growth of plants, but which in excess can cause water to become polluted and threaten aquatic animals.

Nonpoint source pollution - Pollution originating from diffuse areas (land surface or atmosphere) having no well-defined source.

NO_3 - Nitrate.

OMAF (Ontario Ministry of Agriculture and Food) - The Ontario government department that provides extension services and applied research to Ontario's farmers and food industry.

P - Phosphorus. An element occurring in animal manure and chemical fertilizer that is essential to the growth and development of plants, but in excess can cause water to become polluted and threaten aquatic animals.

Pesticide - All-encompassing term for a chemical and organism used in the control of agricultural pests. Pesticides include predators that are specially raised and released to control plant and insect pests. Herbicides are agricultural chemicals for controlling weeds; insecticides are agricultural chemicals for controlling insect pests; fungicides are agricultural chemicals for controlling fungi.

Pesticide Classification
From: Ali, S., J.W. Jones, I.R. Evans, R.C. Acorn. 1992. Crop protection with chemicals, 1992. Alberta Agriculture, Print Media Branch, 7000-113 Street, Edmonton, Alberta T6H 5T6. p. 10-12.

a. Herbicide Classification

Chemical Family	Trade Name	Common Name
Aliphatic Acid	Roundup, Laredo, Wrangler	glyphosate
	NATA	sodium-TCA
Amide	Dual	metolachlor
	Kerb 50W	propyzamide
	Stampede 360	propanil
Amino-propionate	Mataven	flamprop-methyl
Aryl-oxy-phenoxy	Assure	quizalofop-methyl
	Excel Super	fenoxaprop-p-ethyl
	Fusilade II	fluazifop-p-butyl
	Hoe-Grass 284	diclofop-methyl

Chemical Family	Trade Name	Common Name
Benzoic Acid	Banvel, Dycleer	dicamba
Bipyridyliums	Avenge	difenzoquat
	Gramoxone, Sweep	paraquat
	Reglone	diquat
Cyclohexaniones	Achieve	tralkoxydim
	Poast	sethoxydim
Dinitroanilines	Edge	ethalfluralin
	Advance 10G, Heritage, Rival, Treflan, Trifluralin 10G/400, Triflurex	trifluralin
Imidazolinones	Assert	imazamethabenz
Nitriles	Casoran	diclobenil
	Buctril M, Pardner	bromoxynil
Phenoxys	2,4-D	2,4-D
	2,4-DB, Embutox, Cobutox 400	2,4-DB
	Diphenoprop, Estaprop	2,4-D + Diclorprop
	MCPA	MCPA
	Tropotox Plus	MCPB + MCPA
	Mecoprop, Compitox	mecoprop
Picolinic Acid	Lontrel	clopyralid
	Garlon 4, Fencerow, Release	triclopyr
	Tordon	picloram
Sulfonylurea	Ally	metsulfuron methyl
	Express	tribenuron methyl
	Muster	ethametsulfuron methyl
	Refine Extra	ethametsulfuron methyl + tribenuron methyl
Thiocarbarmates	Avadex BW	triallate
	Eptam, Eradicane 8-E	EPTC
	Sutan	butylate
Triazines	Atrazine	atrazine
	Bladex, Blagal	cyanazine
	Lexone, Sencor	metribuzin
	Pronone, Velpar	hexazinone
	Princep Nine-T, Simazine	simazine

Chemical Family	Trade Name	Common Name
Uracils	Basagran	bentazon
	Calmix, Hyvar-X	bromacil
Ureas	Afolan F, Linuron 400, Lorox	linuron
	Karmex	diuron
	Patoran	metobromuron
	Spike	tebuthiuron

b. Insecticide Classification

Chemical Family	Trade Name	Common Name
Carbamates	Temik	aldicarb
	Sevin	carbaryl
	Furadan	carbofuran
	Lannate	methomyl
	Pirimor	pirimicarb
Organochlorines	Lindane	lindane
	Lorsban	chlorpyrifos
	Endosulfan, Thiodan, Thionex	endosulfan
Organophosphates	APM, Guthion	azinphos-methyl
	Diazinon	diazinon
	Cygon, Lagon, Hopper Stopper, Dimethoate	dimethoate
	Dyfonate	fonofos
	Cythion, Malathion	malathion
	Monitor	methamidophos
	Supracide	methidathion
	Dibrom	naled
	Thimet	phorate
	Counter	terbufos
	Dylox	trichlorfon
Phosphides	Gastoxin	aluminum phosphide
Pyrethroids	Cymbush, Ripcord	cypermethrin
	Decis	deltamethrin
	Ambush, Pounce	permethrin

c. Fungicide Classification

Chemical Family	Trade Name	Common Name
Aldehydes	Formalin	formaldehyde
Anilides	Vitavax Single Solution	carbathiin
Benzimidazoles	Benlate, Benolin-R Mertect Easout	benomyl thiabendazole thiophanate-methyl
Dicarboximides	Roval	iprodione
Dithiocarbamates (Carbamates)	Agrox, Dithane M-22, N-M Drill Box, N-M Dual	maneb
	Dithane M-45, Manzate 200, Tuberseal	mancozeb
	Easout	thiophanate-methyl
	Polyram	metiram
	Thiram 75 WP/320	thiram
Organochlorines	Lindane	lindane
Phthalimides	Captan FL/50W	captan
Triazoles	Bayleton Tilt	triadimefon propiconazole

Pesticide management - A Best Management Practice designed to minimize contamination of soil, water, air and nontarget organisms by controlling the amount, type, placement, method and timing of pesticide application necessary for crop production.

Phytoplankton - Algae of open waters (lakes, streams) include groups of blue-green algae that resemble bacteria more than algae. However, all these microbiota use photosynthesis for nutrition. They are the base of the food chain in lakes and rivers.

ppb - parts per billion. Equivalent to milligrams per litre (mg/L).

Runoff - The portion of rainfall or snowmelt that drains off the land into ditches and streams.

Rural Clean Water Program (RCWP) - A federal water quality program in the United States involving 21 watersheds affected by agricultural pollution.

SCS - Soil Conservation Service of the United States Department of Agriculture.

Sediment - Particles and/or clumps of particles of sand, clay, silt, and plant or animal matter carried in water.

Sedimentation - Deposition of sediment.

Sodium Adsorption Ratio (SAR) - A ratio relating the concentration of sodium to the concentration of calcium and magnesium in soil or water. A balance of sodium (Na), calcium and magnesium (a low SAR) is ideal. Excesses of sodium above calcium and magnesium cause clay particles to disperse (slick soils) and then develop a tight, impervious structure. A Solonetzic soil has a high SAR, high pH and a shallow rooting depth to its impermeable layer (B horizon).

Surface water - Water moving over or standing on the earth's surface. In semi-arid climates, like Alberta's, surface water in creeks, rivers and lakes usually has a significant part coming from groundwater inflow. Overland flow (surface flow over fields) is usually limited to snowmelt and very intense rains.

Surfactant - A chemical added to a liquid mixture to promote the emulsifying, dispersing, wetting, spreading, sticking, penetrating or other surface-modifying properties of the liquid. Surfactants are often used with pesticides to enhance their action, e.g. the ability of a herbicide to stick to a weed's leaves.

Trace metals - Elements essential for plant and microorganism growth that are required only in very small quantities. Large quantities are toxic. Molybdenum (Mo), for example, is required at rates of 35 to 70 g/ha but may be toxic at rates of 3,500 g/ha to 4,500 g/ha. Trace metals are copper (Cu), zinc (Zn), magnesium (Mn), iron (Fe) and molybdenum (Mo).

USDA - United States Department of Agriculture.

USLE - Universal Soil Loss Equation, an equation to predict soil loss due to water erosion.

Water management - The practice of slowing down or retaining water in order to decrease runoff and thereby decrease the potential for polluting nearby surface water.

Watershed - The area of land from which rainfall and snowmelt drains into a stream or other water body. Watersheds are sometimes referred to as drainage basins.

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